UNCLASSIFIED

## AD NUMBER

**ADB073386**

## NEW LIMITATION CHANGE

TO

**Approved for public release, distribution unlimited**

FROM

**Distribution limited to U.S. Gov't. agencies and their Contractors; Specific authority; 3 Jan 83. Other requests must be referred to AFWAL/MLTC, Wright-Patterson AFB, OH 45433.**

## AUTHORITY

**Air Force Research Lab ltr., dtd March 27, 2001.**

THIS PAGE IS UNCLASSIFIED

AFWAL-TR-83-4033
VOLUME III

FTR450261000U

# ICAM MANUFACTURING COST/DESIGN GUIDE

## FINAL TECHNICAL REPORT
## AIRFRAMES
## USER'S MANUAL—VOLUME 3

AD B073386

**PERIOD OF PERFORMANCE**
**1 OCTOBER 1979-31 OCTOBER 1982**

**JANUARY 1983**

LIMITED DISTRIBUTION

Distribution limited to United States Government agencies only; Test and Evaluation Data; Statement applied 3 January 1983. Other requests for this document must be referred to AFWAL/MLTC, WPAFB, OH 45433.

FOR EARLY DOMESTIC DISSEMINATION

Because of its significant early commercial potential, this information, which has been developed under a U.S. Government program, is being disseminated within the United States in advance of general publication. This information may be duplicated and used by the recipient with the expressed limitations that it not be published nor released to foreign parties without appropriate export licenses. Release of this information to other domestic parties by the recipient shall be made subject to these limitations. This legend shall be marked on any reproduction of this data in whole or in part.

SUBJECT TO EXPORT CONTROL LAWS

This document contains information for manufacturing or using munitions of war. Export of the information contained herein, or release to foreign nationals within the United States, without first obtaining an export license, is a violation of the International Traffic-in-Arms Regulations. Such violation is subject to a penalty of up to 2 years imprisonment and a fine of $100,000 under 22 USC 2778.

Include this notice with any reproduced portion of this document.

DTIC FILE COPY

**PREPARED FOR:**

**MATERIALS LABORATORY**
**AIR FORCE WRIGHT AERONAUTICAL LABORATORIES**
**AIR FORCE SYSTEMS COMMAND**
**WRIGHT-PATTERSON AFB, OH 45433**

FTR450261000U
3 Jan 1983

# NOTICES

*When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.*

Note that this document bears the label "FEDD", an acronym for "FOR EARLY DOMESTIC DISSEMINATION". The FEDD label is affixed to documents that may contain information having high commercial potential.

The FEDD concept was developed as a result of the desire to maintain U.S. leadership in world trade markets and encourage a favorable balance of trade. Since the availability of tax supported U.S. technology to foreign business interests could represent an unearned benefit, research results that may have high commercial potential are being distributed to U.S. industry in advance of general release.

The recipient of this report must treat the information it contains according to the conditions of the FEDD label on the front cover.

This technical report has been reviewed and is approved for publication.

Richard R. Preston 22 Mar 83

RICHARD R. PRESTON, Capt., USAF
Project Technical Manager
Computer Integrated Manufacturing Br.
Manufacturing Technology Division

N G Tupper

NATHAN G. TUPPER
Chief
Computer Integrated Manufacturing Br.
Manufacturing Technology Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify AFWAL/MLTC, Wright-Patterson AFB, Ohio 45433 to help us maintain a current mailing list."

*Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.*

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
AFWAL-TR-83-4033
VOLUME III

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
FTR450261000U

4. TITLE (and Subtitle)
ICAM "MANUFACTURING COST/DESIGN GUIDE"
FINAL TECHNICAL REPORT
VOLUME III - AIRFRAME MC/DG

5. TYPE OF REPORT & PERIOD COVERED
Final Technical Report Vol III
Oct 1, 1979 - Oct 29, 1982

6. PERFORMING ORG. REPORT NUMBER
00035

7. AUTHOR(s)
Bryan R. Noton, Principal Investigator

8. CONTRACT OR GRANT NUMBER(s)
F33615-79-C-5102

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Battelle's Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Project Priority 4502

11. CONTROLLING OFFICE NAME AND ADDRESS
Computer Integrated Manufacturing Branch
Manufacturing Technology Division (AFWAL/MLTC)
AF Wright Aeronautical Laboratories
Wright-Patterson AFB, Ohio 45433

12. REPORT DATE
January 1983

13. NUMBER OF PAGES
296

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to United States Government agencies only; Test and Evaluation Data; Statement applied January 3, 1983. Other requests for this document must be referred to AFWAL/MLTC, WPAFB, Ohio 45433.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

| | | |
|---|---|---|
| Computer Aided Manufacturing | Fuselage Panels | Extrusions |
| Manufacturing Cost | Sheet Metal Parts | Castings |
| Cost Drivers | Assemblies | Forgings |
| Design-to-Cost | Mechanical Fastening | Test, Inspection & Evaluation |
| Airframe Design | Advanced Composites | |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The "Manufacturing Cost/Design Guide" (MC/DG) enables airframe and electronic designers to achieve lowest cost by conducting trade-offs between manufacturing cost and other design factors. When fully developed, the MC/DG will, for example, permit airframe designers, at all levels of the design process, to quickly perform cost-trade comparisons of manufacturing processes and structural performance/cost trade-offs on airframe components and subassemblies in metallic and composite materials.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (Continued)

The first program, reported in AFML-TR-76-227, developed a model of the MC/DG, the contents, cost drivers, data requirements and designer-oriented formats for conventional and some emerging manufacturing technologies, and also an implementation plan.

The second program (Contract No. F33615-77-C-5027) consisted of four phases in which manufacturing man-hour data and designer-oriented formats were developed for "Sheet-Metal Aerospace Discrete Parts", "First-Level Mechanically Fastened Assemblies", and "Advanced Composite Fabrication". Further, structural performance/manufacturing cost trade-studies were conducted by designers in industry to demonstrate utilization of the manufacturing man-hour data developed in this program.

The data developed by the five participating aerospace companies were normalized by Battelle's Columbus Laboratories and the data plotted in designer-oriented formats. Data have been developed for base parts and discrete parts. The base part is a structural element in its simplest form and when modified with designer-influenced cost elements (DICE) such as joggles, cutouts, and heat treatment, a discrete part ready for assembly is obtained. Typical DICE analyzed for mechanically fastened assemblies are accessibility, material types, part and fastener counts, and sealing requirements. For composites, typical DICE are orientation and number of plies, overlaps, fiber mix, cutouts, and quality requirements.

The data are presented in the series of formats showing cost-driver effects (CDE) and cost-estimating data (CED) and have been evaluated in trade-offs on various fuselage panels designed in titanium, aluminum, and graphite/epoxy.

The third program (Contract No. F33615-79-C-5102) required the development of MC/DG sections on castings, forgings, extrusions, and test, inspection and evaluation (TI&E). Furthermore, as castings, forgings, and extrusions are normally machined prior to assembly in aerospace structures, data and formats were developed for the machining of typical discrete parts manufactured utilizing these methods. TI&E was included in the MC/DG as, in the case of certain materials such as graphite/epoxy and manufacturing methods such as castings, this can be a cost-driver that needs to be included in trade-off studies comparing various manufacturing methods.

The third program also required the development of an MC/DG for electronics fabrication, assembly, and TI&E. A series of typical discrete parts such as transistors, capacitors, diodes, and hybrids were analyzed and also, typical assemblies such as printed wiring boards. Hand, semiautomatic and automatic soldering and insertion processes were also analyzed. Furthermore, the manufacturing cost to meet typical reliability requirements in electronics is also presented to the designer for the selected discrete parts.

20. (Continued)

This project is reported in a six-volume Final Technical Report as follows:

VOLUME I. User's Manual - Airframes Volume 1
Contains:
- Utilization Procedures
- Trade-Off Study Examples
- MC/DG Sections for:
  - Sheet Metal
  - Mechanically Fastened Assembly
  - Composites

VOLUME II. User's Manual - Airframes Volume 2
Contains:
- MC/DG Sections for:
  - Extrusions
  - Castings
  - Forgings

VOLUME III. User's Manual - Airframes Volume 3
Contains:
- MC/DG Test, Inspection & Evaluation Section for:
  - Sheet Metal
  - Mechanically Fastened Assemblies
  - Castings
  - Forgings
  - Machining
  - Composites

VOLUME IV. User's Manual - Electronics Volume 1
Contains:
- Design Process Descriptions
- Conceptual Design Section for:
  - New Technology
  - Number of Assemblies
  - Common Functions
  - Digital Design
  - Built-in Test
  - Part Count
  - Part Selection
    - -- Reliability
    - -- Package
- Detail Design Section for:
  - Mechanization
  - Processes
  - Insertion Process
  - Soldering Process

VOLUME V. Project Summary

VOLUME VI. Technology Transfer Summary and Report Contents

DTIC COPY INSPECTED 2

Accession For
NTIS GRA&I ☐
DTIC TAB ☒
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
B

## FOREWORD

This Manufacturing Cost/Design Guide document covers the work performed under Air Force Contract F33615-79-C-5102 from 1 October 1979 through 1 October 1982. The contract is sponsored by the Computer Integrated Manufacturing Branch, Manufacturing Technology Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories. The ICAM Project Manager is Capt. Richard R. Preston. In previous phases, the following Air Force personnel directed the program; Mr. John R. Williamson, Capt. Dan L. Shunk, and Capt. Steven R. LeClair.

The organization of the program is comprised of a coalition of seven participating companies with Battelle's Columbus Laboratories (BCL) as the prime contractor. Mr. Bryan R. Noton is the BCL Program Manager. The other participating companies of the coalition are listed below:

| Airframe Company Subcontractors | Program Managers |
|---|---|
| General Dynamics Corporation, Fort Worth Division | Ben E. Kaminski<br>Phillip M. Bunting |
| Grumman Aerospace Corporation | Vincent T. Padden<br>Anthony J. Tornabe |
| Honeywell, Incorporated | Robert R. Remski |
| Lockheed-California Company | Anthony J. Pillera<br>John F. Workman |
| Northrop Corporation, Aircraft Group | John R. Hendel<br>Al P. Langlois |
| Rockwell International Corporation, North American Aircraft Operations | Ralph A. Anderson |
| Rockwell International Corporation, Avionics & Missiles Group, Collins Avionics Division | John G. Vecellio |
| In Critique Mode: Boeing Commercial Airplane Company | David Weiss<br>Peter H. Bain |

Note that the number and date in the upper right corner of each page of this document indicates that the document has been prepared according to ICAM's Configuration Management Life Cycle Documentation requirements for Configuration Items (CIs).

Approved by: Bryan R. Noton
BRYAN R. NOTON,
MC/DG Program Manager

AIRFRAME USER'S MANUAL

VOLUME 1

TABLE OF CONTENTS

| | | Page |
|---|---|---|
| SECTION 1. | INTRODUCTION | 1-1 |
| 1.1 | Scope | 1-1 |
| 1.2 | Objectives | 1-3 |
| 1.3 | Designer-Oriented Format Design Criteria | 1-7 |
| 1.4 | Data Presentation Methodologies | 1-9 |
| 1.5 | Data Generation | 1-10 |
| SECTION 2. | REFERENCES | 2-1 |
| 2.1 | Applicable Documents | 2-1 |
| 2.2 | Terms and Abbreviations | 2-3 |
| 2.2.1 | Glossary | 2-3 |
| SECTION 3. | HOW MC/DG IS USED | 3-1 |
| 3.1 | Manufacturing Cost/Design Guide Process Interaction | 3-1 |
| 3.2 | Procedure to Conduct Airframe Trade-Off Studies Utilizing MC/DG | 3-3 |
| 3.3 | Utilization of Learning Curve | 3-6 |
| 3.4 | Cost Worksheet for Airframe Designers | 3-9 |
| 3.4.1 | Instructions for Use of Cost Worksheet | 3-9 |
| SECTION 4. | MANUFACTURING COST/DESIGN GUIDE DATA SECTIONS | 4.1-1 |
| 4.1 | Sheet Metal Section | 4.1-1 |
| 4.1.1 | Format Selection Aids | 4.1-1 |
| 4.1.2 | Building-Block Decisions Utilizing MC/DG | 4.1-5 |
| 4.1.3 | Examples of Utilization | 4.1-9 |
| 4.1.3.1 | Utilization Example for Sheet Metal Aluminum Fairing | 4.1-9 |
| 4.1.3.2 | Utilization Example for Sheet Metal Steel Skin | 4.1-13 |
| 4.1.3.3 | Utilization Example for Titanium Stiffener or Stringer | 4.1-17 |
| 4.1.4 | Sheet Metal Parts Analyzed | 4.1-23 |
| 4.1.5 | Manufacturing Data for Sheet Metal | 4.1-43 |
| 4.1.5.1 | Formats for Aluminum Sheet Metal Aerospace Discrete Parts Lowest Cost Process | 4.1-43 |
| 4.1.5.2 | Formats for Steel Sheet Metal Aerospace Discrete Parts Lowest Cost Processes | 4.1-68 |
| 4.1.5.3 | Formats for Titanium Sheet Metal Aerospace Discrete Parts Lowest Cost Processes | 4.1-79 |
| 4.1.5.4 | Formats for Designer-Influenced Cost Elements (DICE) for Sheet Metal Aerospace Discrete Parts | 4.1-89 |

AIRFRAME USER'S MANUAL

VOLUME 1

TABLE OF CONTENTS
(Continued)

| | | Page |
|---|---|---|
| 4.1.5.5 | Formats for Comparison of Structural Sections Sheet Metal Aerospace Discrete Parts . . . | 4.1-104 |
| 4.1.5.6 | Formats for Comparison of Manufacturing Technologies for Sheet Metal Discrete Parts. . | 4.1-107 |
| 4.1.6 | Ground Rules for Sheet Metal Section . . . . . | 4.1-126 |
| 4.1.6.1 | General Ground Rules . . . . . | 4.1-126 |
| 4.1.6.2 | Detailed Ground Rules. . . . . | 4.1-130 |
| 4.2 | Mechanically Fastened Assembly Section . . . . . | 4.2-1 |
| 4.2.1 | Format Selection Aids. . . . . | 4.2-1 |
| 4.2.2 | Example of Utilization . . . . . | 4.2-3 |
| 4.2.2.1 | Utilization Example of Aluminum First Level Assembly . . . . . | 4.2-3 |
| 4.2.3 | Airframe Assemblies. . . . . | 4.2-9 |
| 4.2.4 | Manufacturing Data for Airframe Assemblies . . | 4.2-15 |
| 4.2.5 | Ground Rules for Mechanically Fastened Assembly Section . . . . . | 4.2-27 |
| 4.2.5.1 | General Ground Rules . . . . . | 4.2-27 |
| 4.2.5.2 | Detailed Ground Rules. . . . . | 4.2-31 |
| 4.3 | Composites Fabrication Section. . . . . | 4.3-1 |
| 4.3.1 | Format Selection Aids. . . . . | 4.3-1 |
| 4.3.2 | Example of Utilization . . . . . | 4.3-3 |
| 4.3.2.1 | Utilization Example for Graphite/Epoxy "I" Section. . . . . | 4.3-3 |
| 4.3.3 | Parts Analyzed . . . . . | 4.3-9 |
| 4.3.4 | Composite Materials Data . . . . . | 4.3-12 |
| 4.3.5 | Ground Rules for Advanced Composites Section . | 4.3-38 |
| 4.3.5.1 | General Ground Rules . . . . . | 4.3-38 |
| 4.3.5.2 | Detailed Ground Rules. . . . . | 4.3-42 |

AIRFRAME USER'S MANUAL

VOLUME 2

TABLE OF CONTENTS

| | | Page |
|---|---|---|
| SECTION 4. | MANUFACTURING COST/DESIGN GUIDE DATA SECTIONS | |
| 4.4 | Extrusion Section. . . . . | 4.4-1 |
| 4.4.1 | Format Selection Aids. . . . . | 4.4-1 |
| 4.4.2 | Example of Utilization . . . . . | 4.4-5 |
| 4.4.2.1 | Material Cost for Aluminum Extrusions. | 4.4-5 |
| 4.4.2.2 | Material Cost for Titanium/Steel Extrusions . . . . . | 4.4-5 |
| 4.4.2.3 | Cost of Aluminum Extrusion . . . . . | 4.4-6 |
| 4.4.2.4 | Cost of Titanium Extrusion . . . . . | 4.4-7 |
| 4.4.3 | Parts Analyzed . . . . . | 4.4-17 |
| 4.4.4 | Extrusion Manufacturing Cost Data. . . . | 4.4-22 |
| 4.4.5 | Ground Rules for Extrusions Section. . . | 4.4-49 |
| 4.4.5.1 | General Ground Rules . . . . . | 4.4-49 |
| 4.4.5.2 | Detailed Ground Rules. . . . . | 4.4-53 |
| 4.5 | Casting Section. . . . . | 4.5-1 |
| 4.5.1 | Format Selection Aids. . . . . | 4.5-1 |
| 4.5.2 | Example of Utilization . . . . . | 4.5-5 |
| 4.5.2.1 | Utilization Example for Bell Crank . . | 4.5-5 |
| 4.5.3 | Cast Parts Analyzed. . . . . | 4.5-28 |
| 4.5.4 | Data for Castings. . . . . | 4.5-32 |
| 4.5.5 | Ground Rules for Castings Section. . . . | 4.5-61 |
| 4.5.5.1 | General Ground Rules . . . . . | 4.5-61 |
| 4.5.5.2 | Detailed Ground Rules. . . . . | 4.5-65 |
| 4.6 | Forging Section. . . . . | 4.6-1 |
| 4.6.1 | Format Selection Aids. . . . . | 4.6-1 |
| 4.6.2 | Example of Utilization . . . . . | 4.6-5 |
| 4.6.2.1 | Utilization Example for Aluminum Precision Forging. . . . . | 4.6-5 |
| 4.6.3 | Parts Analyzed . . . . . | 4.6-19 |
| 4.6.4 | Forging Manufacturing Cost Data. . . . . | 4.6-31 |
| 4.6.5 | Ground Rules for Forging Section . . . . | 4.6-68 |
| 4.6.5.1 | General Ground Rules . . . . . | 4.6-68 |
| 4.6.5.2 | Detailed Ground Rules. . . . . | 4.6-72 |

AIRFRAME USER'S MANUAL

VOLUME 3

TABLE OF CONTENTS

| | | Page |
|---|---|---|
| SECTION 4. | MANUFACTURING COST/DESIGN GUIDE DATA SECTIONS | |
| 4.7 | Test, Inspection & Evaluation Section. . . | 4.7.1-1 |
| 4.7.1 | TI&E for Sheet Metal . . . . . | 4.7.1-1 |
| 4.7.1.1 | Format Selection Aids. . . . . | 4.7.1-1 |
| 4.7.1.2 | Utilization Examples of Test, Inspection and Evaluation (TI&E) Section. . . . | 4.7.1-4 |
| 4.7.1.2.1 | Example of Utilization for Aluminum Fairing. . . . . | 4.7.1-4 |
| 4.7.1.2.2 | Utilization Example for Steel Skin . | 4.7.1-8 |
| 4.7.1.2.3 | Utilization Example for Titanium "Z" | 4.7.1-12 |
| 4.7.1.3 | Data for TI&E of Sheet Metal . . . . . | 4.7.1-16 |
| 4.7.1.4 | Ground Rules for Test, Inspection and Evaluation (TI&E) for Sheet Metal Section. . . . . | 4.7.1-66 |
| 4.7.1.4.1 | General Ground Rules . . . . . | 4.7.1-66 |
| 4.7.1.4.2 | Detailed Ground Rules. . . . . | 4.7.1-69 |
| 4.7.2 | TI&E for Mechanically Fastened Assemblies | 4.7.2-1 |
| 4.7.2.1 | Format Selection Aids. . . . . | 4.7.2-1 |
| 4.7.2.2 | Example of Utilization . . . . . | 4.7.2-3 |
| 4.7.2.2.1 | Utilization Example for Mechanically Fastened Assembly. . . . . | 4.7.2-3 |
| 4.7.2.3 | Airframe Assemblies Analyzed . . . . . | 4.7.2-10 |
| 4.7.2.4 | TI&E Data for Airframe Assemblies. . . | 4.7.2-10 |
| 4.7.2.5 | Ground Rules for Test, Inspection and Evaluation (TI&E) of Mechanically Fastened Assemblies Section. . . . . | 4.7.2-15 |
| 4.7.2.5.1 | General Ground Rules . . . . . | 4.7.2-15 |
| 4.7.2.5.2 | Detailed Ground Rules. . . . . | 4.7.2-18 |
| 4.7.3 | TI&E for Castings. . . . . | 4.7.3-1 |
| 4.7.3.1 | Format Selection Aids. . . . . | 4.7.3-1 |
| 4.7.3.2 | Example of Utilization . . . . . | 4.7.3-1 |
| 4.7.3.2.1 | Utilization Example for Bell Crank . | 4.7.3-1 |
| 4.7.3.3 | Casting Parts Analyzed . . . . . | 4.7.3-3 |
| 4.7.3.4 | TI&E Data for Castings . . . . . | 4.7.3-3 |
| 4.7.3.5 | Ground Rules for Castings Section. . . | 4.7.3-16 |
| 4.7.3.5.1 | General Ground Rules . . . . . | 4.7.3-16 |
| 4.7.3.5.2 | Detailed Ground Rules. . . . . | 4.7.3-20 |
| 4.7.4 | TI&E for Forgings. . . . . | 4.7.4-1 |
| 4.7.4.1 | Format Selection Aid . . . . . | 4.7.4-1 |
| 4.7.4.2 | Example of Utilization . . . . . | 4.7.4-3 |

AIRFRAME USER'S MANUAL

VOLUME 3

TABLE OF CONTENTS
(Continued)

| | | Page |
|---|---|---|
| SECTION 4. | MANUFACTURING COST/DESIGN GUIDE DATA SECTIONS. | |
| 4.7.4.2.1 | Utilization Example for Titanium Hand Forging. . . . . | 4.7.4-3 |
| 4.7.4.2.2 | Utilization Example for Aluminum Rolled Ring Forging. . . . . | 4.7.4-8 |
| 4.7.4.3 | Parts Analyzed . . . . . | 4.7.4-12 |
| 4.7.4.4 | TI&E Data for Forgings . . . . . | 4.7.4-12 |
| 4.7.4.5 | Ground Rules for TI&E - Forging Section. | 4.7.4-16 |
| 4.7.4.5.1 | General Ground Rules . . . . . | 4.7.4-16 |
| 4.7.4.5.2 | Detailed Ground Rules. . . . . | 4.7.4-20 |
| 4.7.5 | TI&E for Machining . . . . . | 4.7.5-1 |
| 4.7.5.1 | Format Selection Aids. . . . . | 4.7.5-1 |
| 4.7.5.2 | Example of Utilization . . . . . | 4.7.5-3 |
| 4.7.5.2.1 | Utilization Example for Aluminum Frame | 4.7.5-3 |
| 4.7.5.3 | Airframe Parts Analyzed. . . . . | 4.7.5-9 |
| 4.7.5.4 | TI&E Data for Machined Parts . . . . . | 4.7.5-15 |
| 4.7.5.5 | Ground Rules for Test, Inspection and Evaluation (TI&E) of Machining Section | 4.7.5-37 |
| 4.7.5.5.1 | General Ground Rules . . . . . | 4.7.5-37 |
| 4.7.5.5.2 | Detailed Ground Rules. . . . . | 4.7.5-40 |
| 4.7.6 | TI&E for Composites. . . . . | 4.7.6-1 |
| 4.7.6.1 | Format Selection Aid . . . . . | 4.7.6-1 |
| 4.7.6.2 | Composite Parts Analyzed . . . . . | 4.7.6-3 |
| 4.7.6.3 | TI&E Data for Composites . . . . . | 4.7.6-7 |
| 4.7.6.4 | Ground Rules for Test, Inspection and Evaluation (TI&E) of Advanced Composites Section . . . . . | 4.7.6-25 |
| 4.7.6.4.1 | General Ground Rules . . . . . | 4.7.6-25 |
| 4.7.6.4.2 | Detailed Ground Rules. . . . . | 4.7.6-27 |
| 4.8 | Integrated Trade-Studies Using MC/DG . . . . | 4.8-1 |
| 4.8.1 | Scope of Trade-Studies . . . . . | 4.8-1 |
| 4.8.2 | Aluminum Fuselage Panel. . . . . | 4.8-3 |
| 4.8.3 | Titanium Fuselage Panel. . . . . | 4.8-20 |
| 4.8.4 | Composite Fuselage Panel . . . . . | 4.8-47 |
| 4.9 | Supplementary Forms. . . . . | 4.9-1 |
| 4.9.1 | Worksheets for Designer Use. . . . . | 4.9-1 |
| 4.9.2 | Document Request Order Form. . . . . | 4.9-1 |

## 4.7 Test, Inspection & Evaluation (TI&E) Section

This section contains format selection aids, identification of the types of parts analyzed for data to determine the manufacturing man-hour data, examples of how the data are utilized in airframe design and a set of MC/DG formats. These formats include cost-driver effects (CDE), cost-estimating data (CED) and designer-influenced cost elements (DICE).

### 4.7.1 TI&E for Sheet Metal

#### 4.7.1.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide cost-driver effects (CDE) for qualitative guidance to the lowest cost and cost-estimating data (CED) in man-hours for conducting trade-studies.

# FORMAT SELECTION AID
## TEST, INSPECTION AND EVALUATION (TI&E)
## SHEET-METAL AEROSPACE DISCRETE PARTS

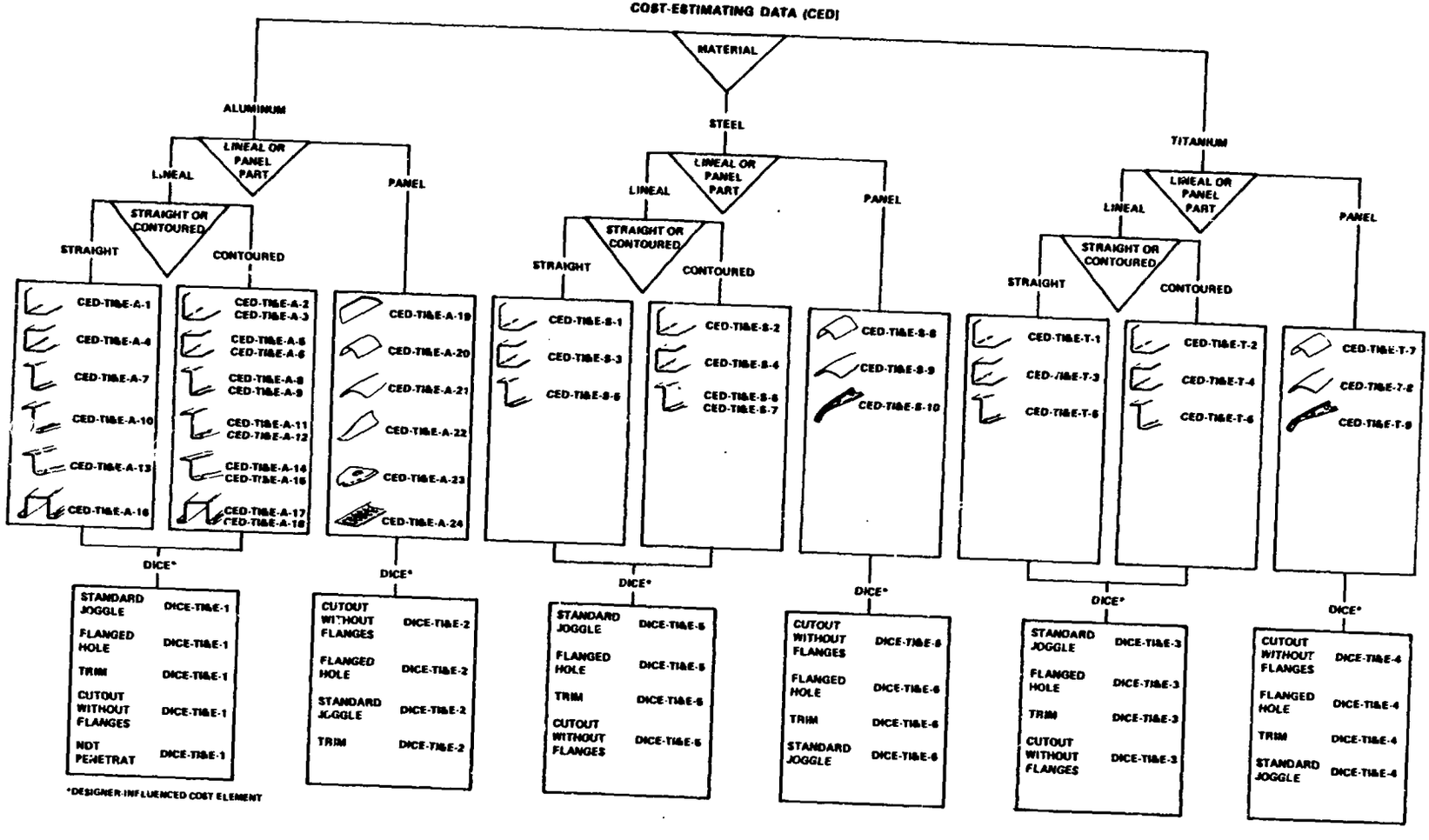



FIGURE 4.7.1-1

# FORMAT SELECTION AID
# TEST, INSPECTION AND EVALUATION (TI&E)
## SHEET-METAL COST-DRIVER EFFECT (CDE) DATA

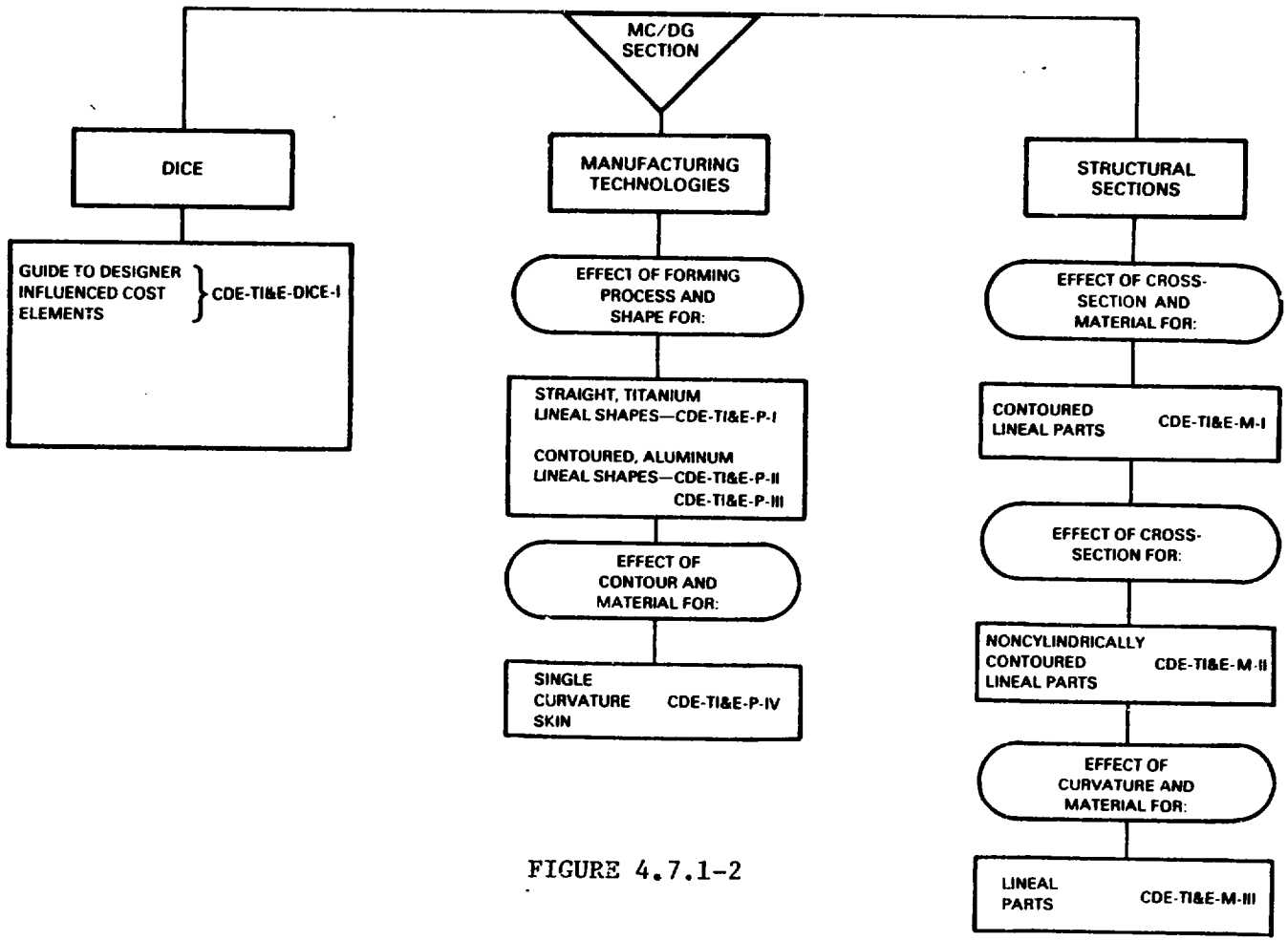



FIGURE 4.7.1-2

### 4.7.1.2 Utilization Examples of Test, Inspection and Evaluation (TI&E) Section

#### 4.7.1.2.1 Example of Utilization for Aluminum Fairing

**Problem Statement**

Determine test, inspection and evaluation (TI&E) cost (man-hours) of an aluminum (2024) fairing of deminsions: 36" x 12"; see sketch below. The order will be for 200 parts.

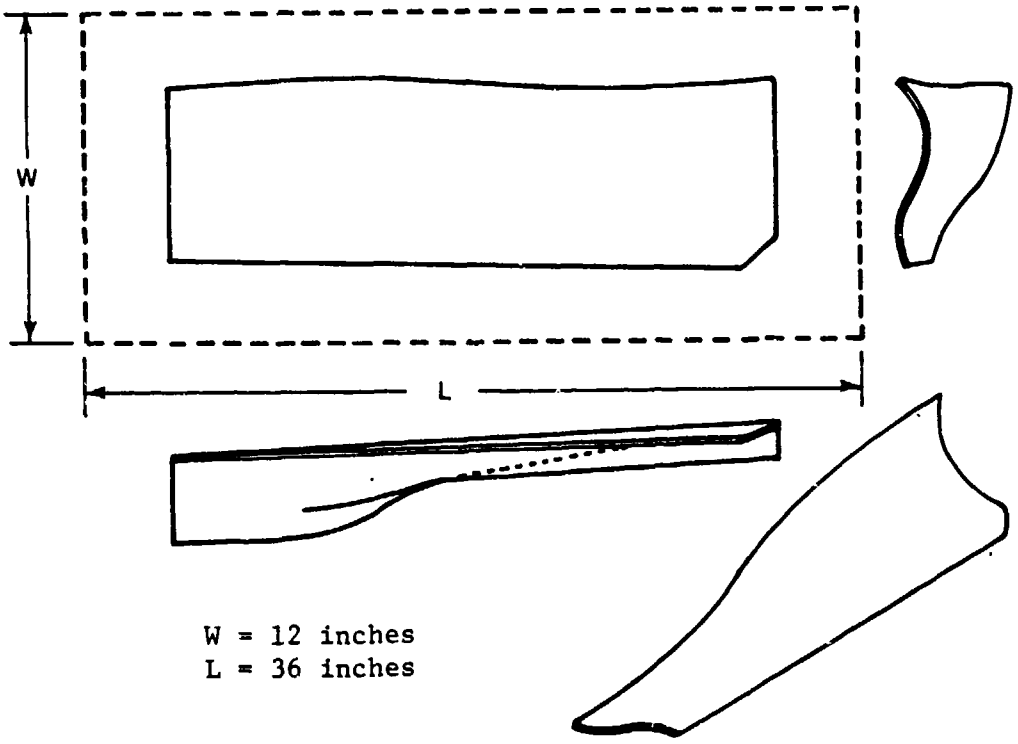



FIGURE 4.7.1-3 ALUMINUM FAIRING ANALYZED

**Procedure**

The following procedure is used to determine the TI&E cost of the aluminum fairing.

1. Utilize the Format Selection Aid for Sheet Metal TI&E (Figure 4.7.1-1 and Figure 4.7.1-2).
2. Determine the format to use. In this case, Format CED-TI&E-A-22 (Figure 4.7.1-4) is required.
3. Study the format to determine the parameters and conditions necessary for its use and relate these to the part. For CED-TI&E-A-22 area (square feet) is needed, in this case 3 $ft^2$.
4. From CED-TI&E-A-22, read values for the recurring cost and nonrecurring tooling cost (NRTC):

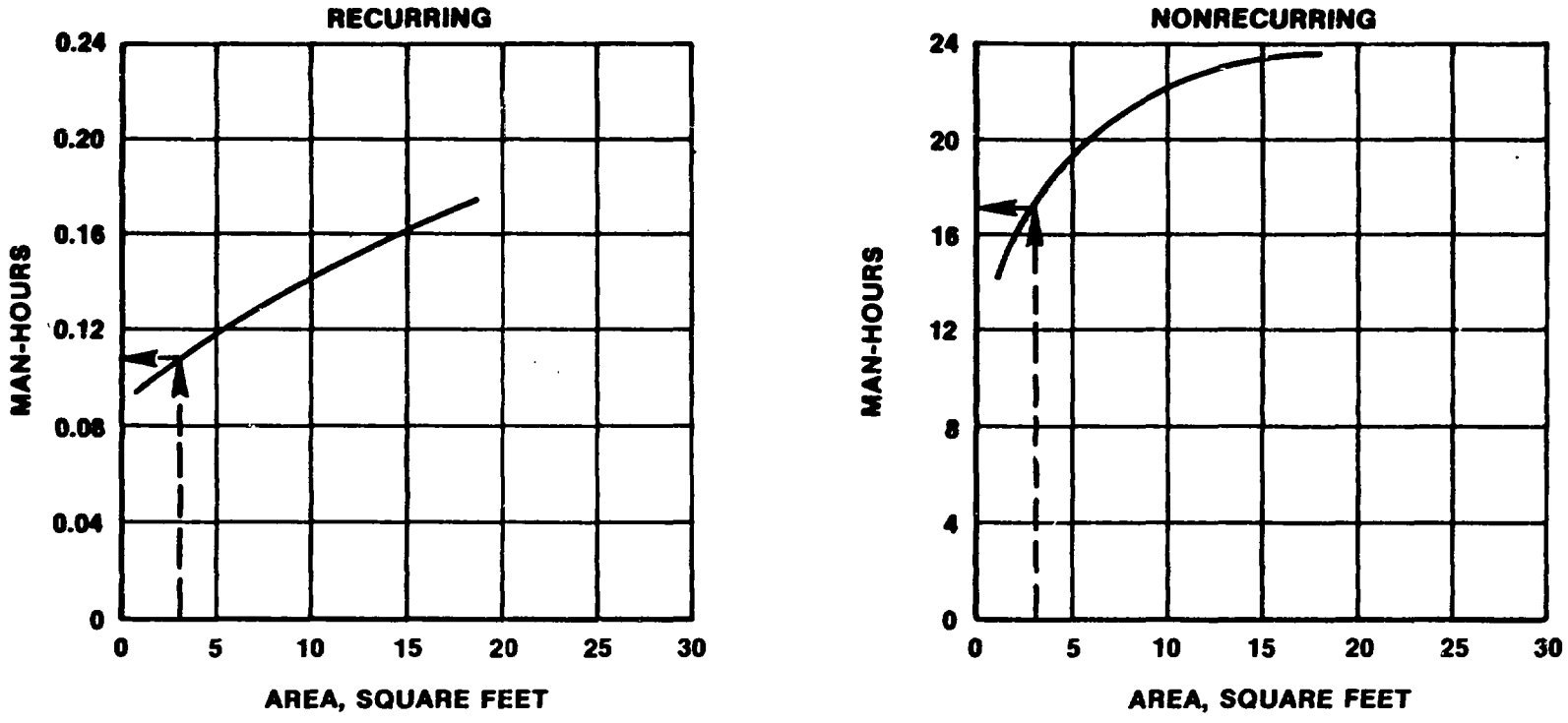
- Recurring cost at unit 200 = 0.11 man-hours per part
- NRTC = 17.2 man-hours for 200 parts or 17.2/200 = 0.086 ∿ 0.09 man-hours per part
- The learning curve factor to convert unit cost at 200 to cumulative average cost for a 90 percent curve and a quantity of 200 is 1.17 (see Table 4.7.1-1).

The base part TI&E cost is thus 0.11 (1.17) + 0.09 = 0.22 man-hours per part.

5. Check for applicable Designer-Influenced Cost Elements (DICE). Format indicates that DICE-D is applicable for TI&E of the drop hammer manufacturing method for producing part. Since the part drawing does not indicate any cutouts, there are no additional DICE-TI&E charges. This implies that the calculated base part TI&E cost is the final test, inspection and evaluation cost for the discrete part.

6. Obtain the cost (dollars) by multiplying 0.22 man-hours by the applicable labor rate at your company.

# TI&E
# ALUMINUM FAIRING
# DROP HAMMER




APPLICABLE DICE (D)

**CED-TI&E-A-22**

FIGURE 4.7.1-4. FORMAT USED IN EXAMPLE

TABLE 4.7.1-1

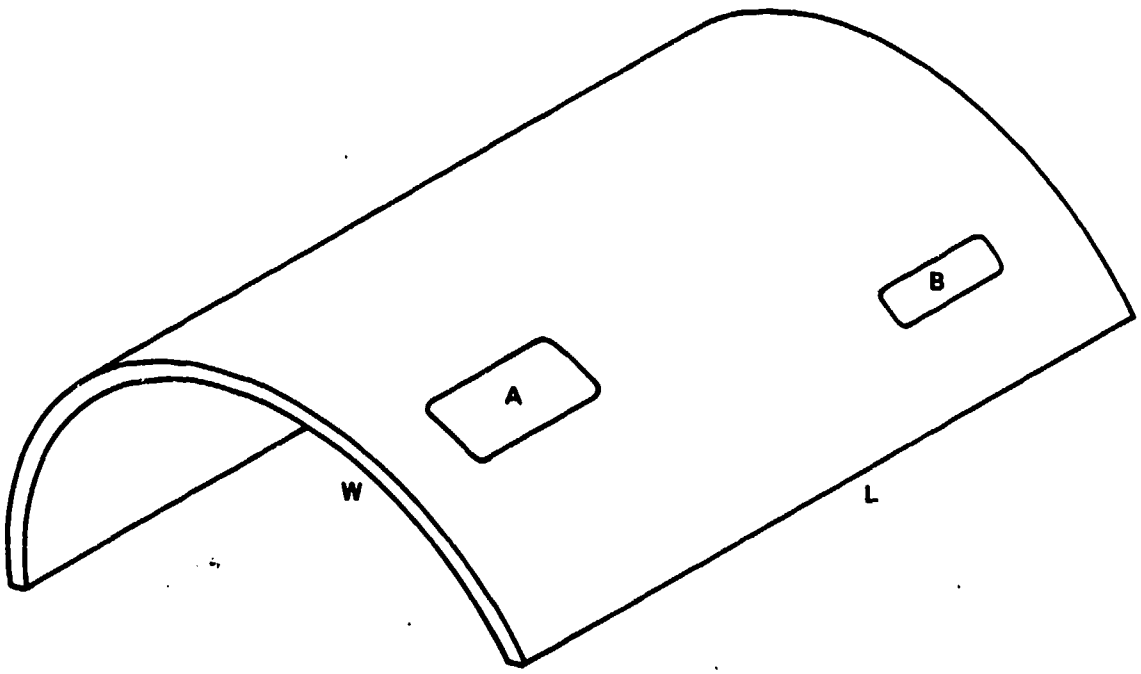
## FACTORS TO CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED

| DESIGN QUANTITY | LEARNING CURVE-% | | | | | | |
|---|---|---|---|---|---|---|---|
| | 95 | 90 | 85 | 80 | 75 | 70 | 65 |
| 1 | 1.48 | 2.25 | 3.48 | 5.50 | 9.00 | 15.00 | 27.00 |
| 10 | 1.33 | 1.79 | 2.47 | 3.48 | 5.04 | 7.53 | 11.67 |
| 25 | 1.25 | 1.59 | 2.05 | 2.71 | 3.68 | 5.13 | 7.43 |
| 50 | 1.19 | 1.44 | 1.79 | 2.22 | 2.85 | 3.76 | 5.14 |
| 100 | 1.13 | 1.30 | 1.52 | 1.80 | 2.18 | 2.73 | 3.51 |
| 200 | 1.08 | 1.17 | 1.30 | 1.45 | 1.66 | 1.95 | 2.36 |
| 350 | 1.04 | 1.08 | 1.14 | 1.22 | 1.33 | 1.48 | 1.70 |
| 500 | 1.01 | 1.02 | 1.05 | 1.09 | 1.15 | 1.24 | 1.38 |
| 750 | 0.98 | 0.96 | 0.96 | 0.96 | 0.97 | 1.01 | 1.09 |
| 1000 | 0.96 | 0.92 | 0.89 | 0.87 | 0.87 | 0.88 | 0.91 |

### 4.7.1.2.2 Utilization Example for Steel Skin

**Problem Statement**

Determine test, inspection and evaluation (TI&E) cost (man-hours) of a PH15-7Mo steel skin, having circular and two cutouts, as shown below:




**Dimensions:**

- Sheet developed size: 60" (length)
  36" (width)
- Cutouts: A: 12"x6"
  B: 4"x8"

FIGURE 4.7.1-5. STEEL SKIN ANALYZED

**Procedure**

The following procedure is used to determine the TI&E cost of the steel skin.

1. Utilize the Format Selection Aid for Sheet Metal TI&E (Figure 4.7.1-1 and -2).
2. Determine the formats to use. In this case, Formats CED-TI&E-S-8 (Fig. 4.7.1-6) for skin and DICE-TI&E-6 (Table 4.7.1-2) for the cutouts are applicable.
3. Study the formats to determine the parameters and conditions necessary for their use. In this case, the area is required in square feet, i.e., 15 $ft^2$.

4. From CED-TI&E-S-8 determine the base part recurring and non-recurring tooling costs (NRTC) in man-hours.

   - Recurring cost at unit 200 = 0.13 man-hours per part
   - NRTC = 2.2 man-hours for 200 parts = 0.11 ∿ 0.01 man-hours per part
   - Learning curve factor = 1.17 (see Table 4.7.1-1).

   Therefore, the base part TI&E cost is: 0.13 (1.17) + 0.01 = 0.16 man-hours.

5. Analyze the manufacturing cost for Designer-Influenced Cost Elements (DICE). For this discrete part, cutouts (DICE-D) are called out on the drawing. Format CED-TI&E-S-8 indicates that DICE-D is applicable for TI&E of the Farnham Roll manufacturing method. Therefore, Format DICE-TI&E-6 is required to determine the inspection cost of the cutouts.

   DICE-TI&E-6 indicates that inspection of a standard cutout requires 0.016 man-hours per cutout. The drawing shows two cutouts, thus the total DICE TI&E cost is 2 x 0.016 = 0.032 man-hours.

6. Determine the test, inspection, and evaluation cost for the discrete part by adding 0.16 + 1.17 (0.032) = 0.20 man-hours per part.

# TI&E DICE—SHEET METAL NON-LINEAL SHAPES

## STEEL

### TI&E MAN-HOURS PER CHARACTERISTIC INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Cylindrically Contoured Skin<br>• Farnham Roll | All | | | | 0.016 | 0.010 | | |
| • Non-Cylindrically Contoured Skin<br>• Stretch Form | All | | | | 0.016 | 0.010 | | |
| • Frame<br>• Rubber Press | All | 0.012 | 0.008 | | 0.010 | 0.010 | | |

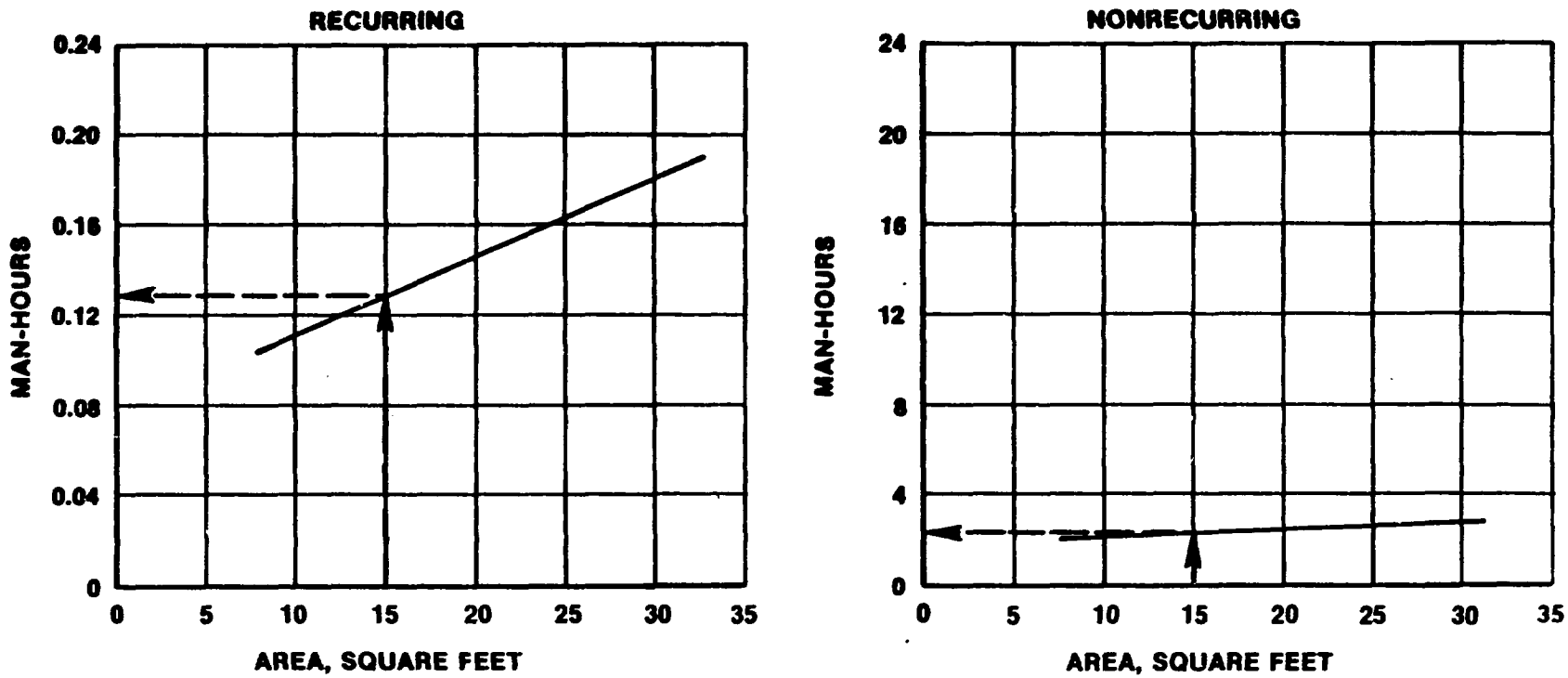
A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

FIGURE 4.7.1-6. FORMAT USED IN EXAMPLE

DICE-TI&E-6

# TI&E
# STEEL CYLINDRICAL CURVATURE SKIN
# FARNHAM ROLL




APPLICABLE DICE (D,E)

CED-TI&E-S-8

FIGURE 4.7.1-7. FORMAT USED IN EXAMPLE

### 4.7.1.2.3 Utilization Example for Titanium "Z"

**Problem Statement**

Determine test, inspection and evaluation (TI&E) cost (man-hours) of a straight 6Al-4V titanium "Z" section stringer, having the dimensions shown on the sketch on the following page.

**Procedure**

The following procedure is used to determine the TI&E cost for the titanium "Z" section.

1. Utilize the Format Selection Aid for Sheet Metal TI&E (page (Figures 4.7.1-1 and -2).
2. Determine the appropriate format for the base part; in this case CED-TI&E-T-5 (Figure 4.7.1-7).
3. Study the format to determine the parameters and conditions required for use. In this case, part length, in feet, and bend radius are needed. For the purposes of this example, consider that either of the bend radius ranges indicated on the format could be used, and determine which design would have the lowest TI&E cost. Thus, we have the following two cases for the part:

   (a) Part length = 84 in. = 7 ft
   Bend radius (R) $\geq$ 5 t.

   (b) Part length = 84 in. = 7 ft
   Bend radius (R) $2t \leq R \leq 5t$.

4. Determine the base part recurring and nonrecurring tooling costs (NRTC) (man-hours) for each case using CED-TI&E-T-5 and the learning curve factor of 1.17 from Table 4.7.1-1:

   (a) Using curve (1)

   - Recurring cost at unit 200 = 0.08 man-hour per part
   - NRTC = 5 man-hours per 200 parts
     = 0.025 man-hour per part.

   Base-part cost = 0.08 (1.17) + 0.025 = 0.119 man-hour per part.

   (b) Using curve (2)

   - Recurring cost at unit 200 = 0.08 man-hour per part
   - NRTC = 21 man-hours per 200 parts
     = 0.105 man-hour per part.

   Base-Part Cost = 0.08 (1.17) + 0.105 = 0.199 man-hour.

5. Check for applicable DICE. The example has flanged lightening holes (DICE-B) and trim prior to forming.

   For Case (a), Format CED-TI&E-T-5 (Fig. 4.7.1-7) shows that DICE-B and DICE-E are applicable to TI&E of the brake forming method.

   For Case (b), the format indicates that the same DICE are applicable for TI&E of the preform/hot size method as for the brake formed part.

   DICE costs for Cases (a) and (b) are found by again utilizing the Format Selection Aid and determining that Format DICE-TI&E-3 (Table 4.7.1-3) is applicable. The parameters required are the number of flanged holes and number of trims. Eight flanged holes are required in the airframe part and the number of trims required is five. The TI&E DICE costs are:

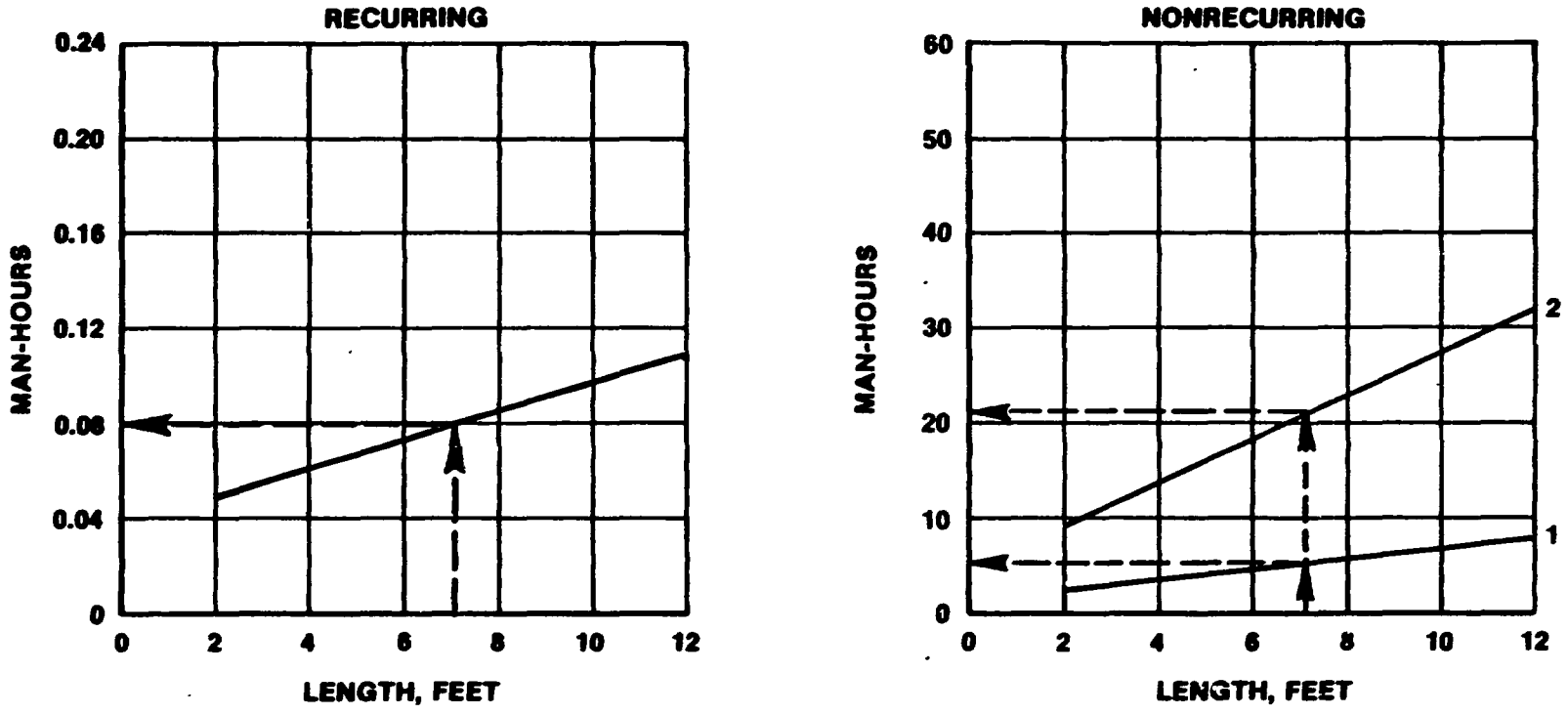
   - Flanged holes: 0.006 x 8 = 0.048 man-hours per part
   - Trim prior to forming: 0.010 x 5 = 0.050 man-hour per part.

6. Determine total TI&E costs (man-hours):

   - Case (a): 1.17 (0.08 + 0.048 + 0.050) + 0.025 = 0.223 man-hours
   - Case (b): 1.17 (0.08 + 0.048 + 0.050) + 0.105 = 0.313 man-hours.

   This shows that it is less costly to test, inspect and evaluate the part with a bend radius of $\geq$ 5t, if the design constraints permit the utilization of this part.

# TI&E
# TITANIUM ZEE, STRAIGHT MEMBER
# BRAKE FORM OR PREFORM/HOT SIZE




APPLICABLE DICE (A,B,D,E)

1. ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS ≐ 5t.
2. PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t.

**CED-TI&E-T-5**

FIGURE 4.7.1-8. FORMAT USED IN EXAMPLE

# TI&E DICE—SHEET METAL LINEAL SHAPES

## TITANIUM

### TI&E MAN-HOURS PER CHARACTERISTIC INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Straight<br>• Brake Formed<br>• Room Temperature | All | 0.007 | 0.006 | | 0.006 | 0.010 | | |
| • Straight<br>• Preform and Hot Size | All | 0.007 | 0.006 | | 0.006 | 0.010 | | |
| • Contoured<br>• Preform and Hot Size | All | 0.012 | 0.008 | | 0.010 | 0.010 | | |
| • Contoured<br>• Brake and Hot Stretch | All | 0.008 | 0.007 | | | 0.010 | | |

A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

**NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.**

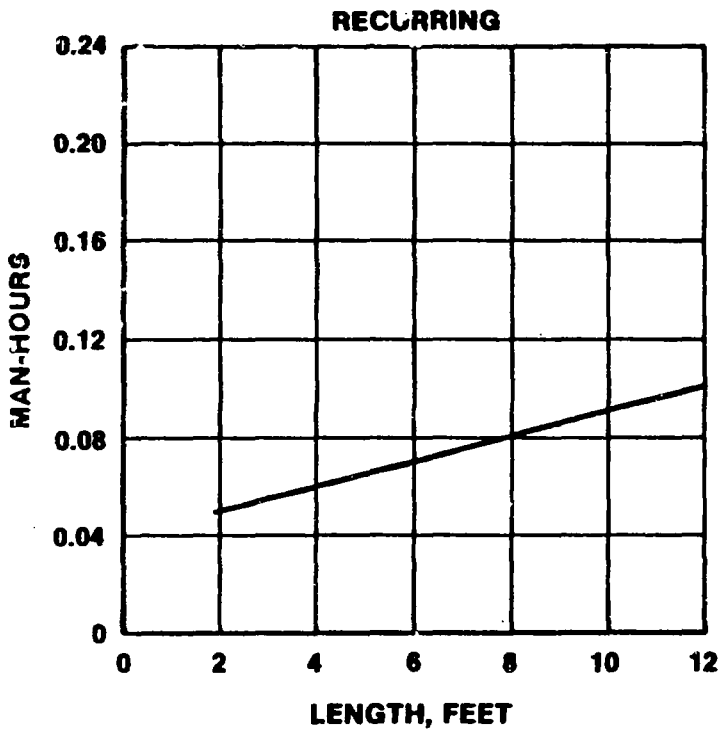
FIGURE 4.7.1-9. FORMAT USED IN EXAMPLE

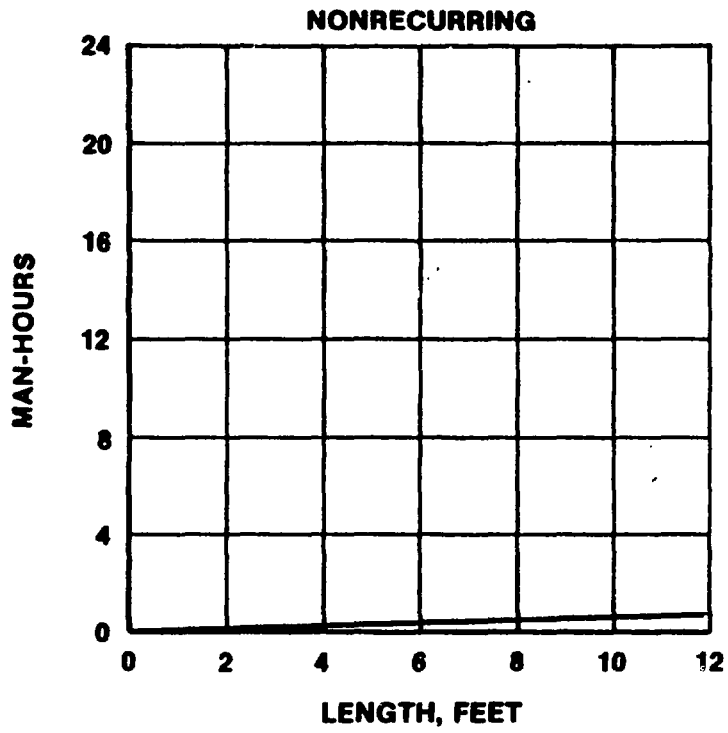
DICE-TI&E-3

### 4.7.1.3 Data for TI&E of Sheet Metal

The data on the following pages provide designer guidance to lowest costand enable trade-off studies to be conducted. The data indicates the impact of TI&E on discrete part cost. The data is for aluminum, titanium, and steel.

# TI&E
# ALUMINUM ANGLE, STRAIGHT MEMBER
# BRAKE FORM

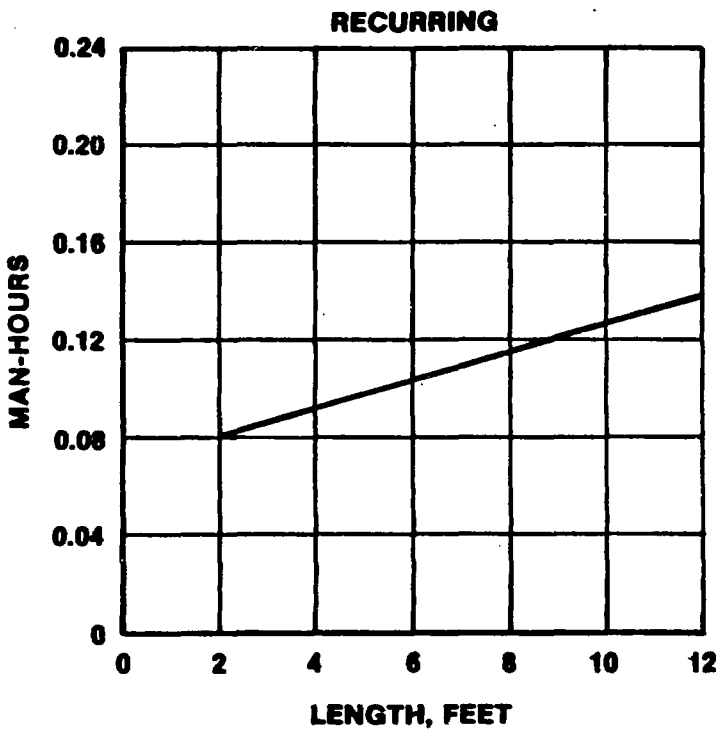


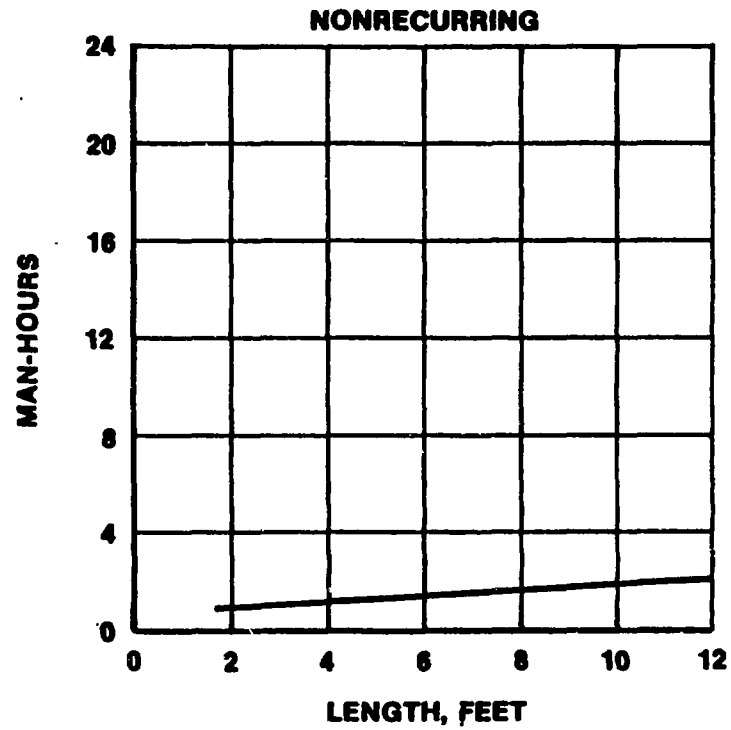




APPLICABLE DICE (A,B,D)

CED-TI&E-A-1

# TI&E
# ALUMINUM ANGLE, CYLINDRICALLY CONTOURED
# BRAKE/ROLL

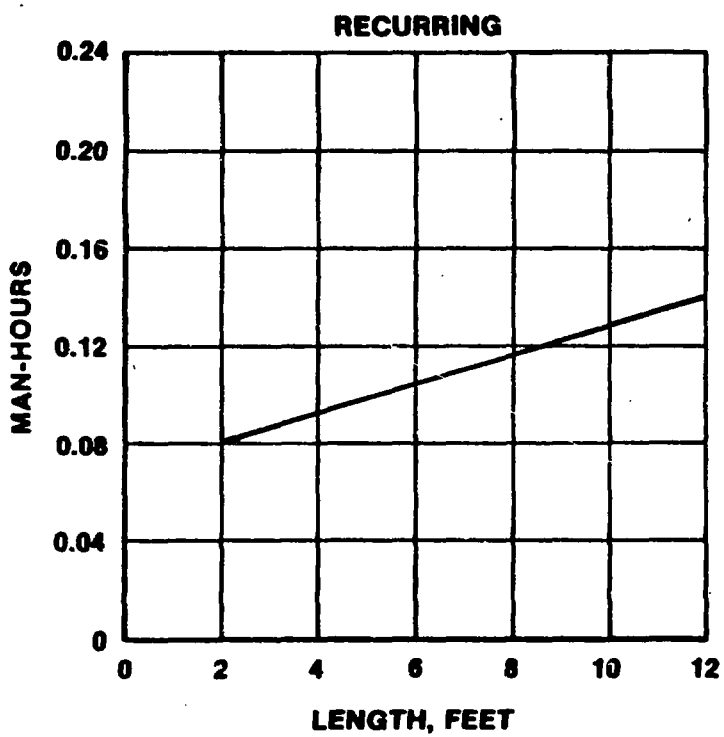


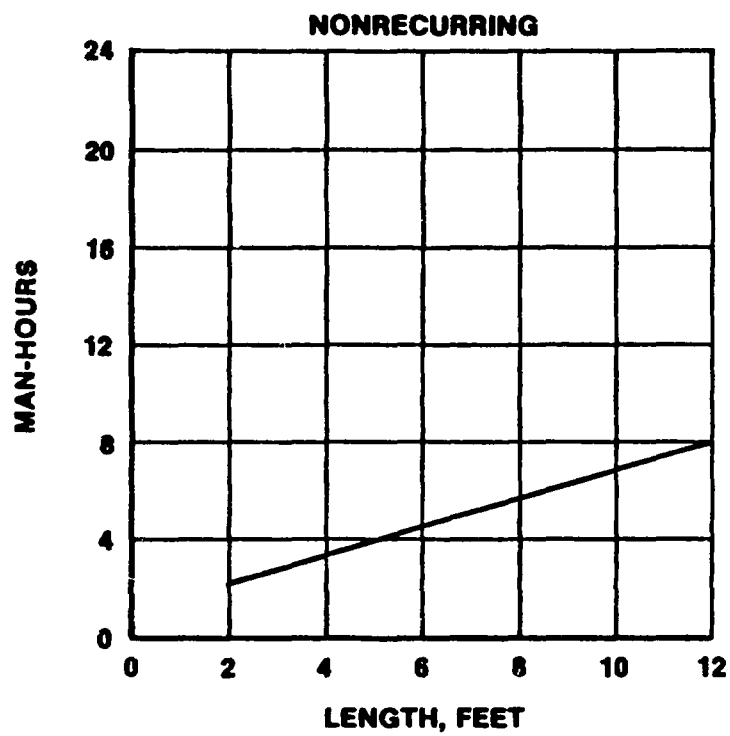




APPLICABLE DICE (A,B,E,G)

CED-TI&E-A-2

# TI&E
# ALUMINUM ANGLE, NONCYLINDRICALLY CONTOURED*
# RUBBER PRESS




*NO REVERSE CURVATURE

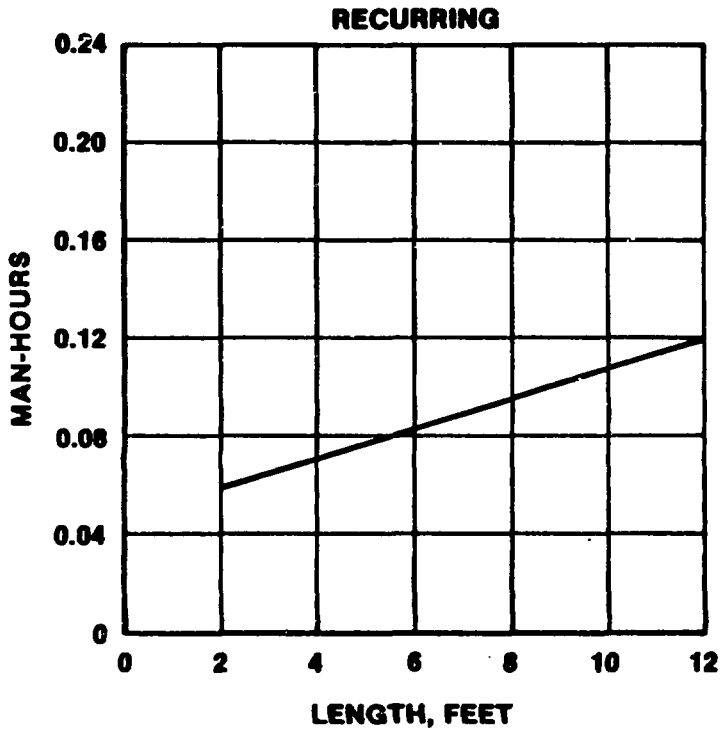
APPLICABLE DICE (A,B,D,E,G)

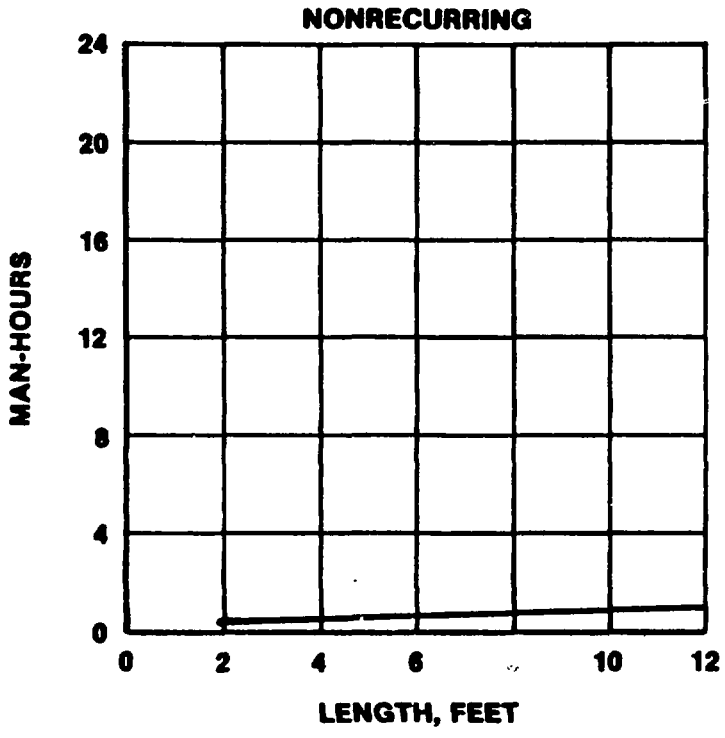
CED-TI&E-A-3



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM CHANNEL, STRAIGHT
# BRAKE FORM



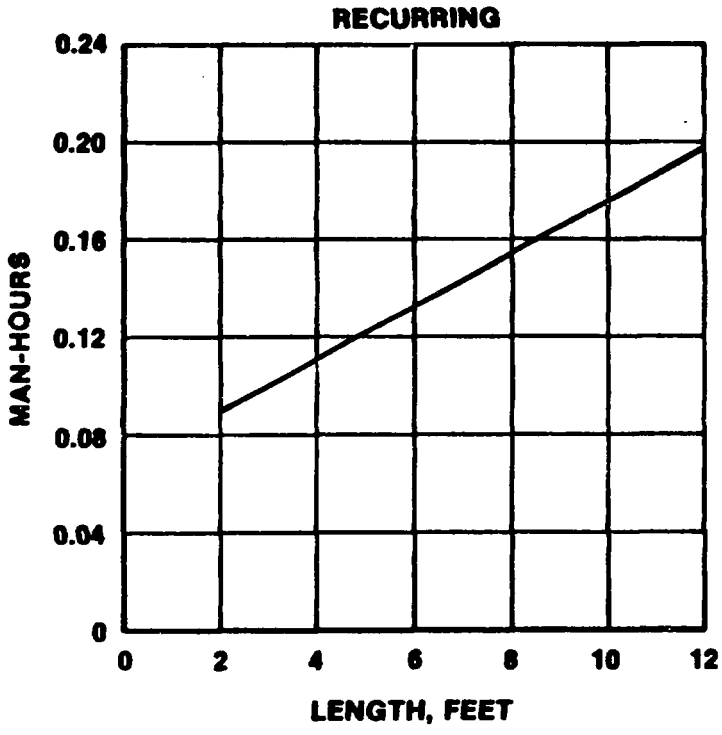

APPLICABLE DICE (A,B,D)

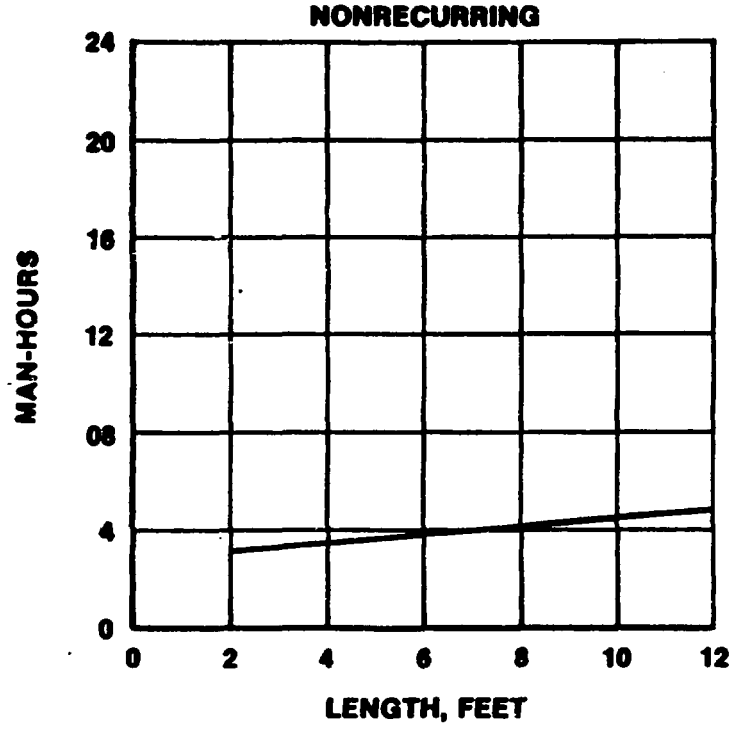
CED-TI&E-A-4



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM CHANNEL, CYLINDRICALLY CONTOURED
# BRAKE/ROLL



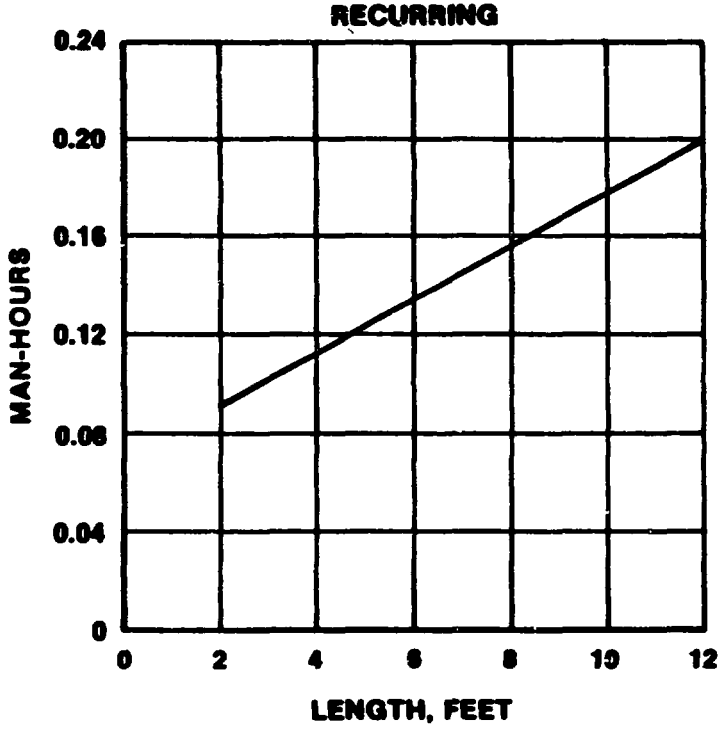

APPLICABLE DICE (A,B,E,G)

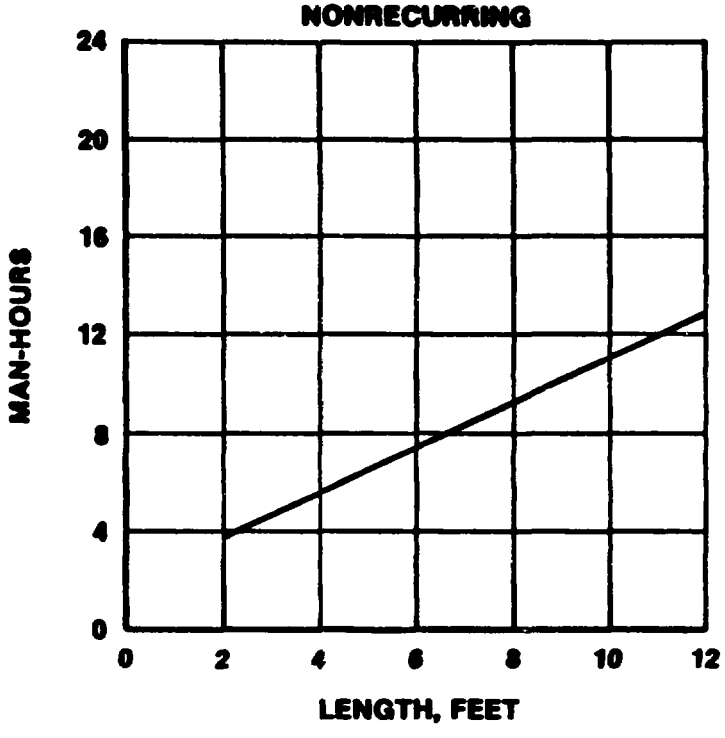
CED-TI&E-A-5



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM CHANNEL, NONCYLINDRICALLY CONTOURED*
# RUBBER PRESS




*NO REVERSE CURVATURE

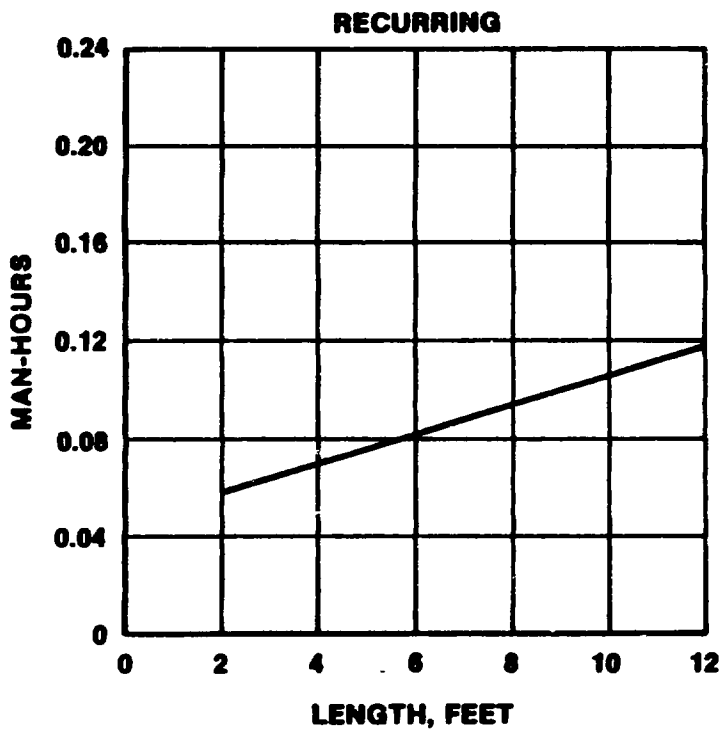
APPLICABLE DICE (A,B,D,E,G)

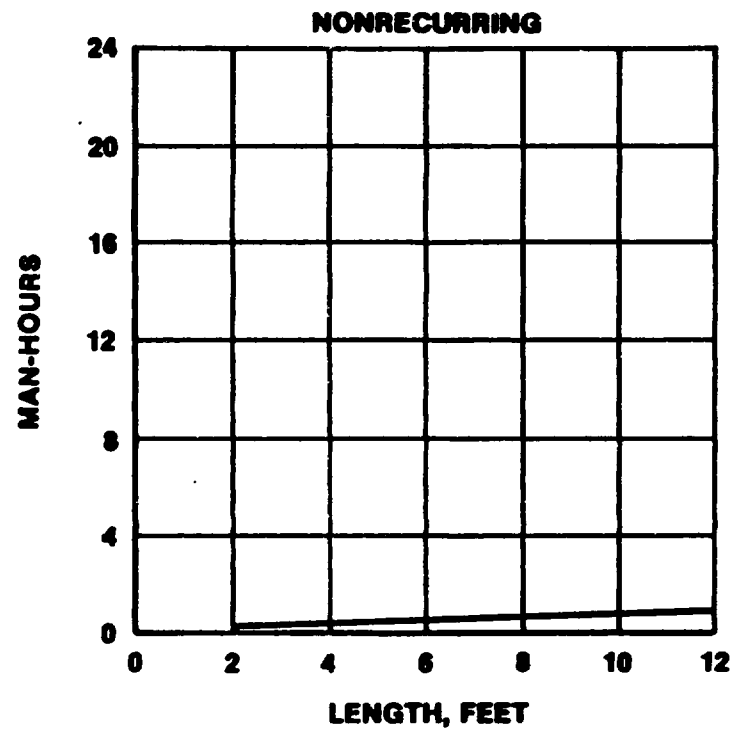
CED-TI&E-A-6



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM ZEE, STRAIGHT
# BRAKE FORM



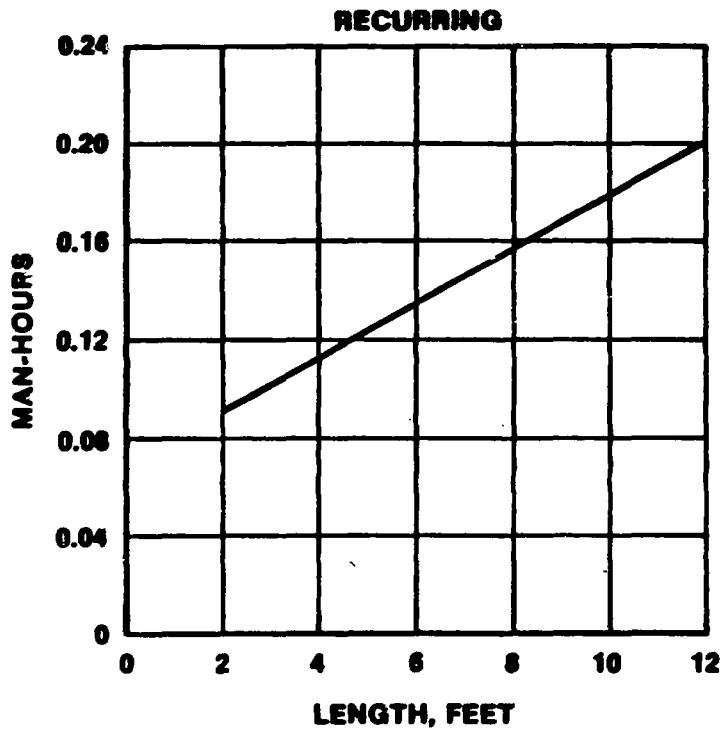

APPLICABLE DICE (A,B,D)

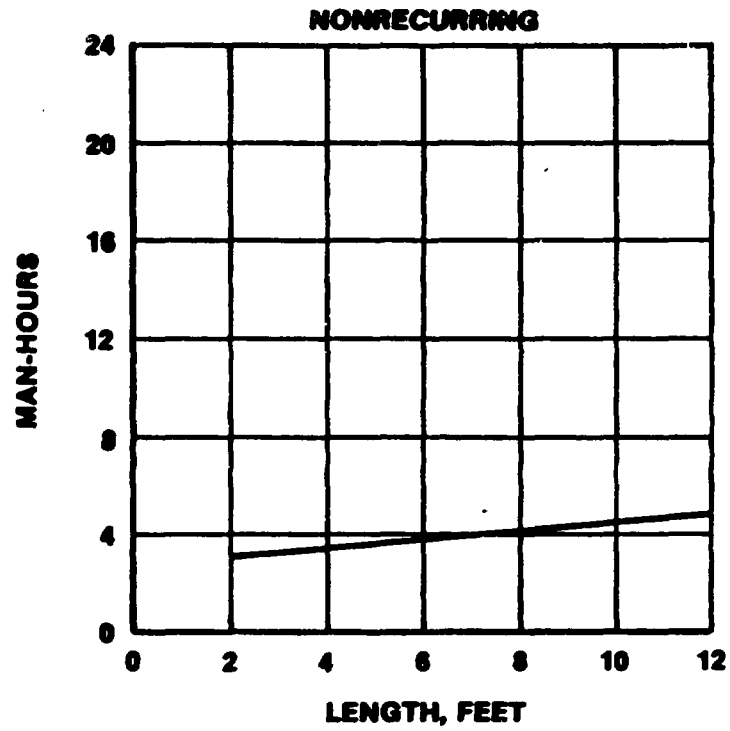
CED-TI&E-A-7



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM ZEE, CYLINDRICALLY CONTOURED BRAKE/ROLL



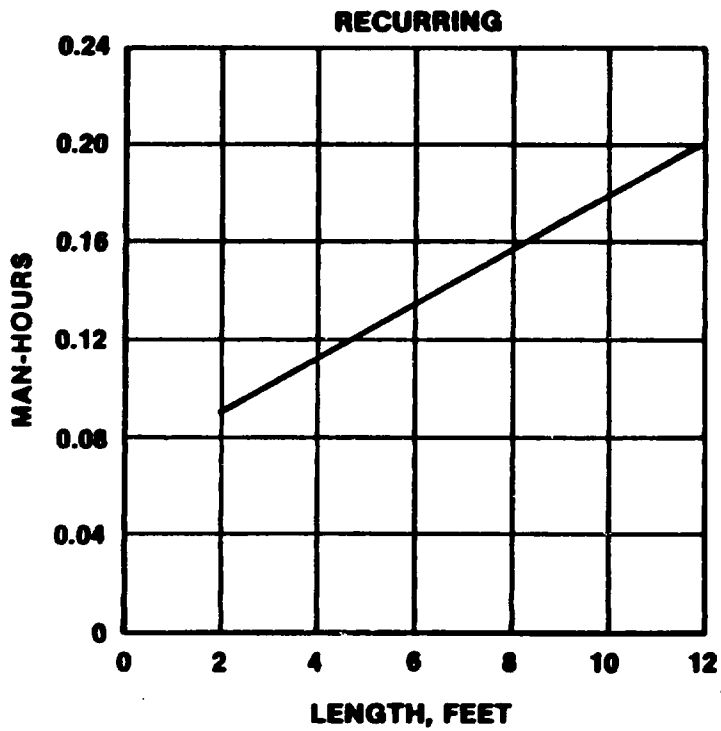

APPLICABLE DICE (A,B,E,G)

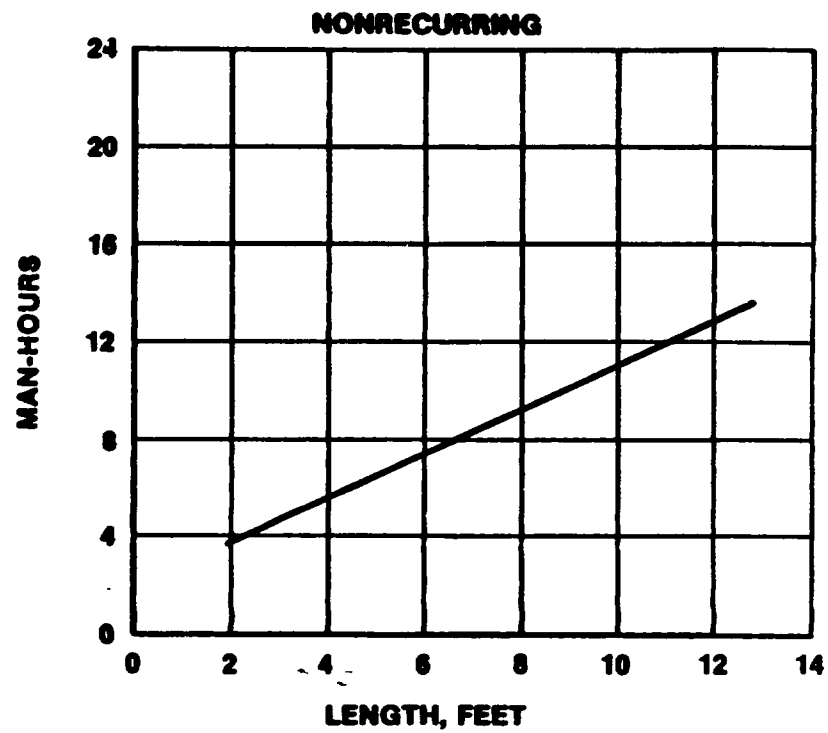
**CED-TI&E-A-8**



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM ZEE, NONCYLINDRICALLY CONTOURED*
# RUBBER PRESS



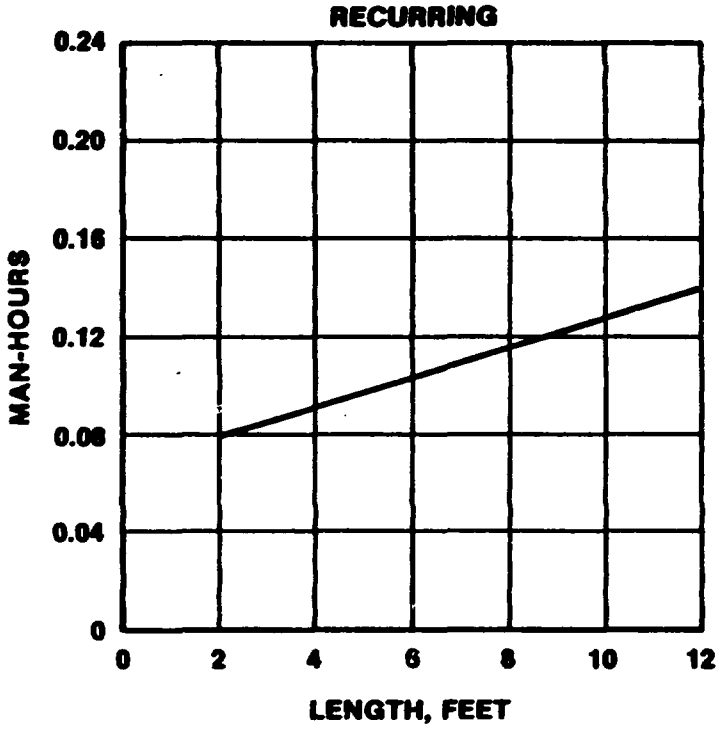



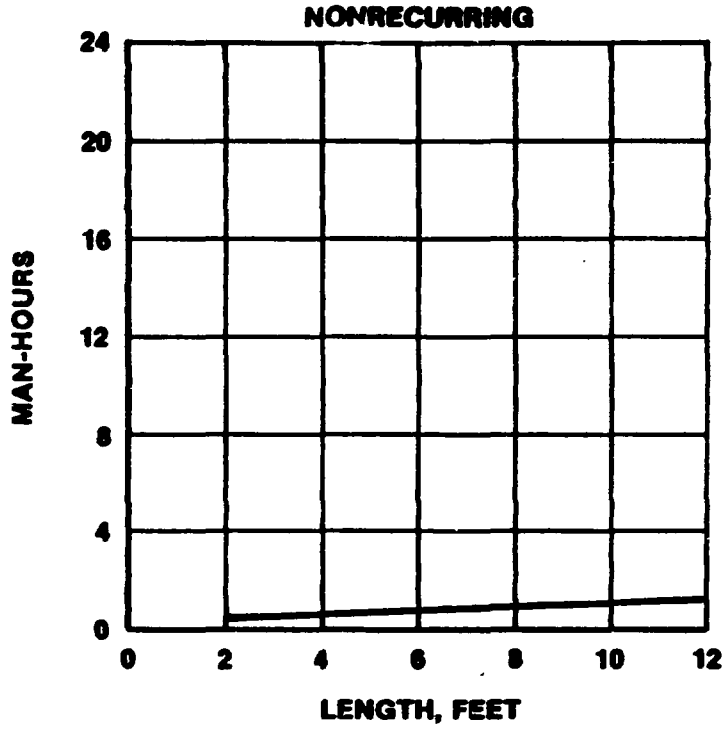

*NO REVERSE CURVATURE

APPLICABLE DICE (A,B,D,E,G)

**CED-TI&E-A-9**

# TI&E
# ALUMINUM LIPPED ZEE, STRAIGHT
# BRAKE FORM

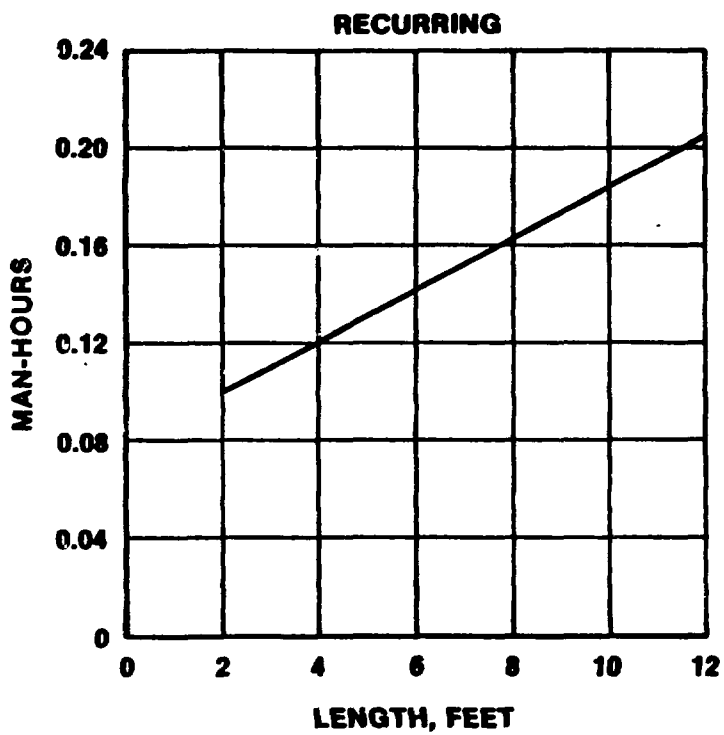


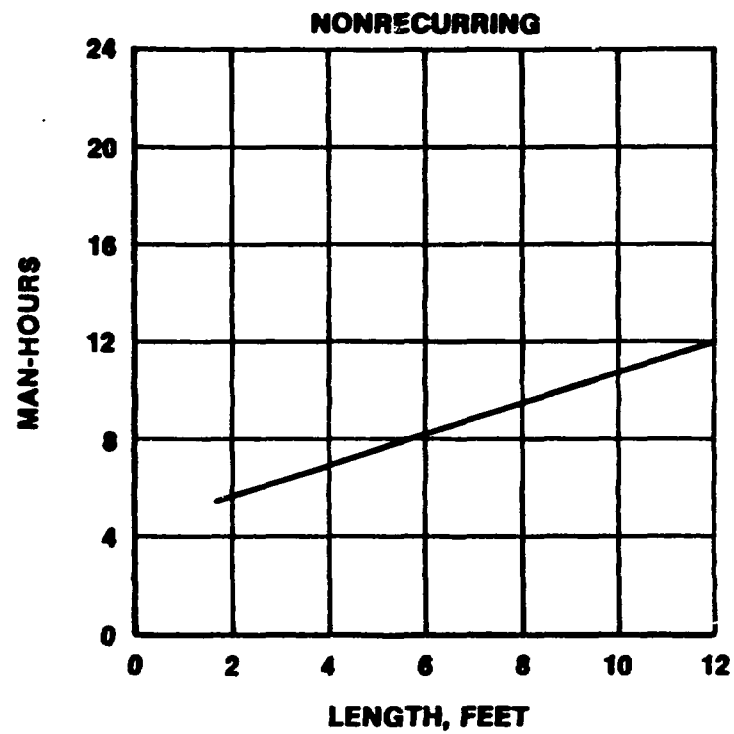




APPLICABLE DICE (A,B,D)

**CED-TI&E-A-10**

# TI&E
# ALUMINUM LIPPED ZEE, CYLINDRICALLY CONTOURED BRAKE/ROLL

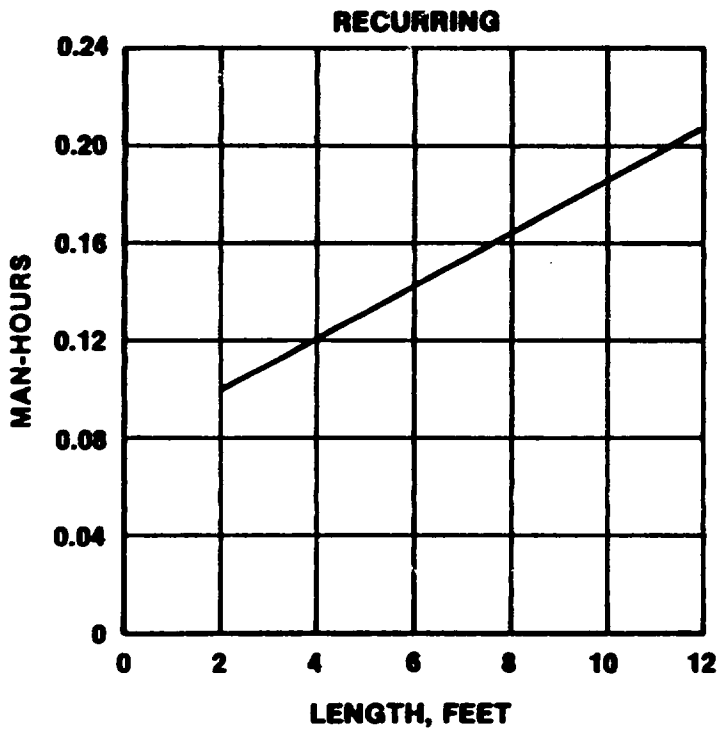


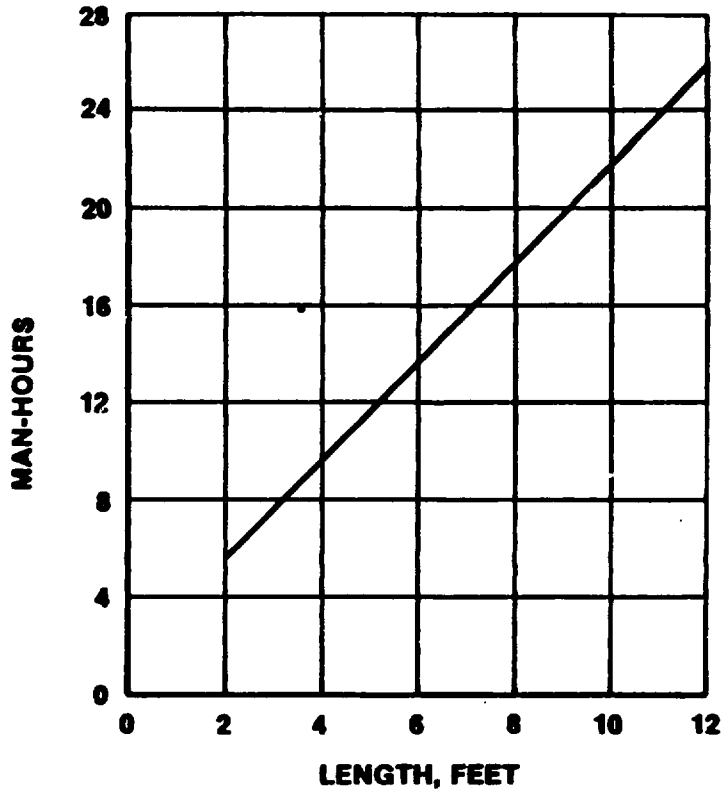




APPLICABLE DICE (A,B,E,G)

**CED-TI&E-A-11**

# TI&E
# ALUMINUM LIPPED ZEE, NONCYLINDRICALLY CONTOURED* BRAKE/STRETCH



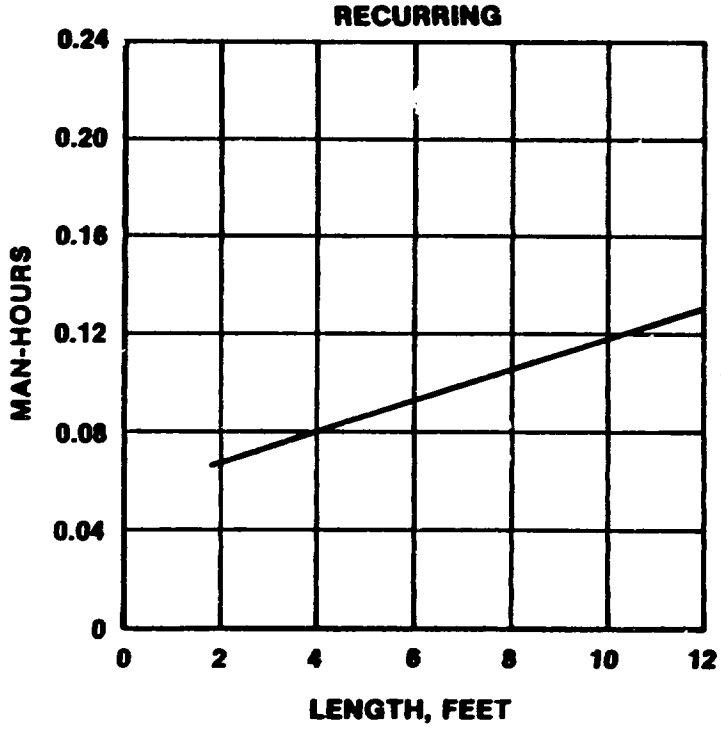



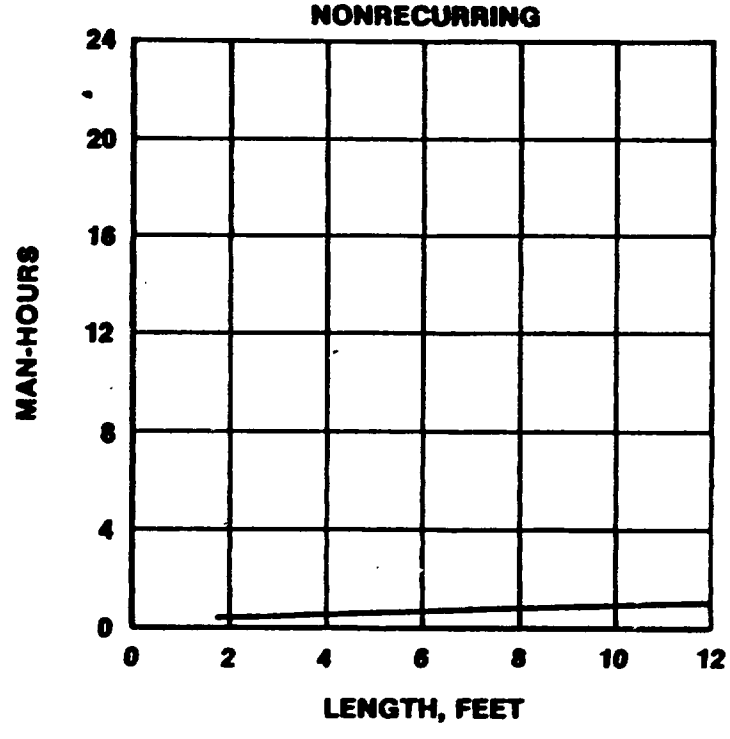

*NO REVERSE CURVATURE

APPLICABLE DICE (A,B,E,G)

**CED-TI&E-A-12**

# TI&E
# ALUMINUM J, STRAIGHT
# BRAKE FORM



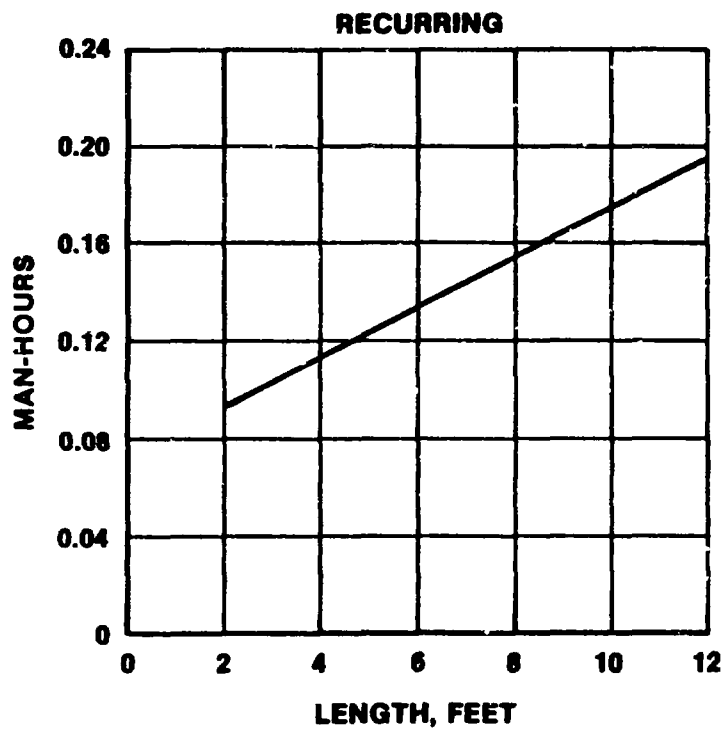

APPLICABLE DICE (A,B,D)

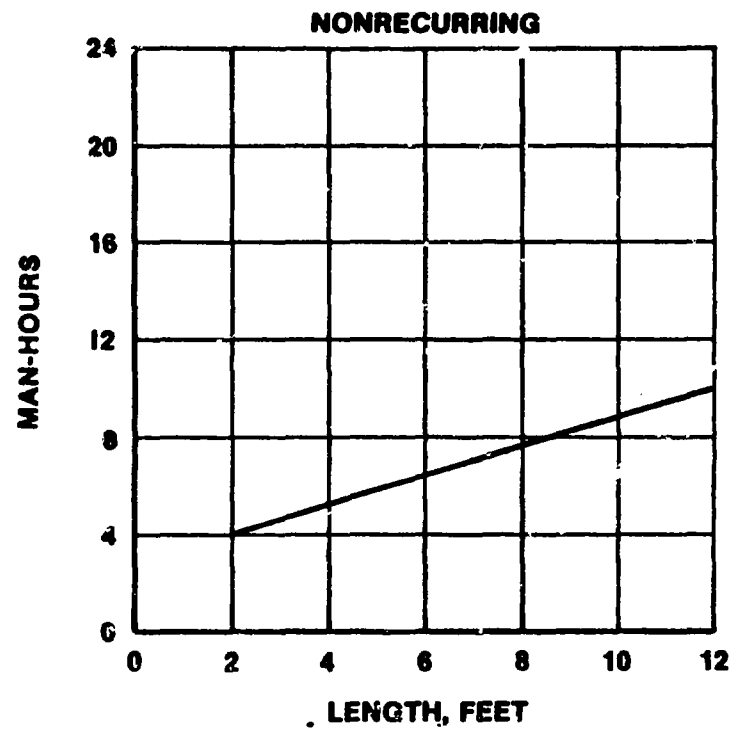
CED-TI&E-A-13



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM J, CYLINDRICALLY CONTOURED BRAKE/ROLL

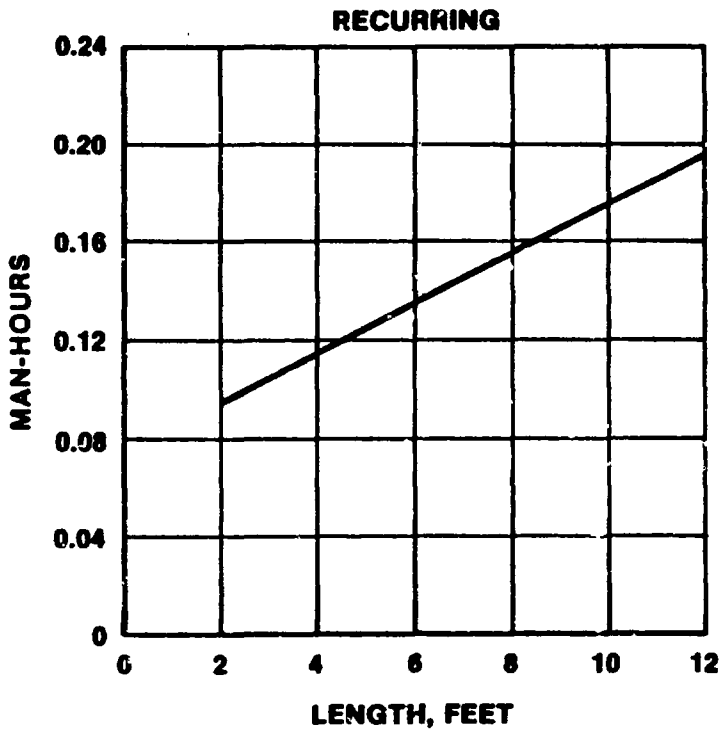


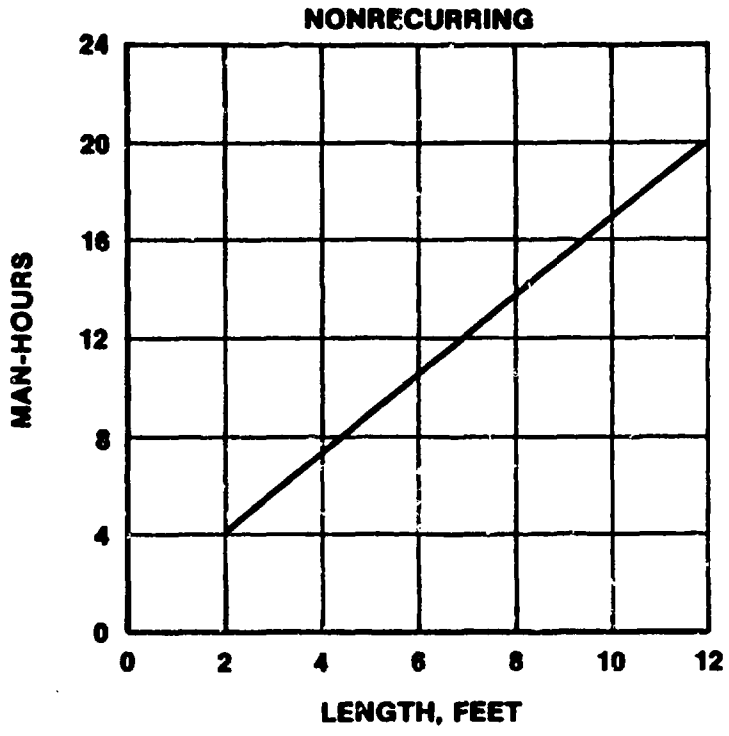




APPLICABLE DICE (A,B,E,G)

CED-TI&E-A-14

# TI&E
# ALUMINUM J, NONCYLINDRICALLY CONTOURED*
# BRAKE/STRETCH



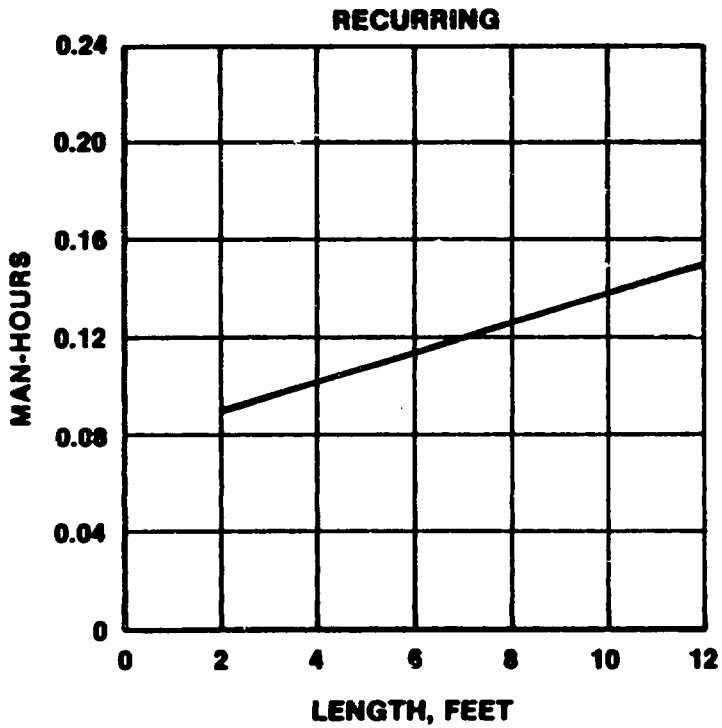



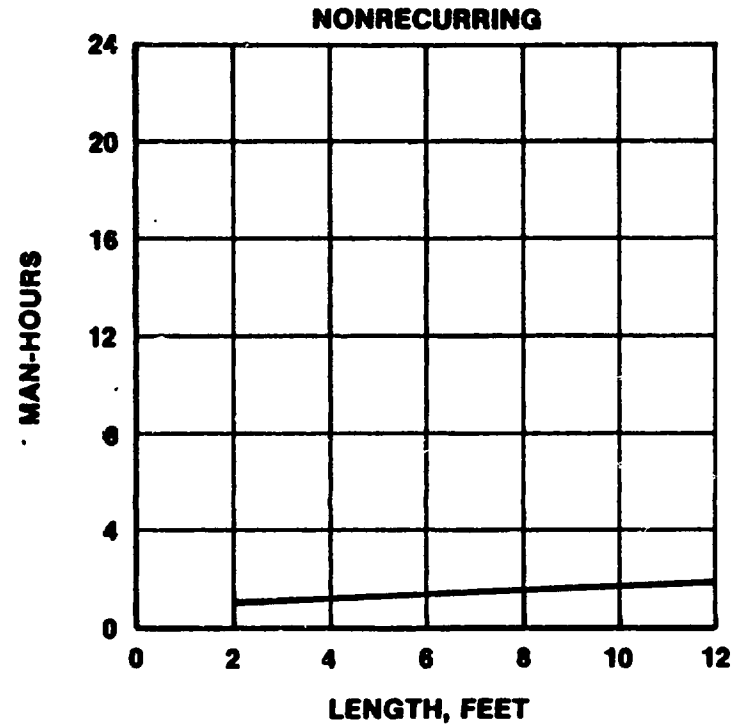

*NO REVERSE CURVATURE

APPLICABLE DICE (A,B,E,G)

CED-TI&E-A-15

# TI&E
# ALUMINUM LIPPED HAT, STRAIGHT
# BRAKE FORM

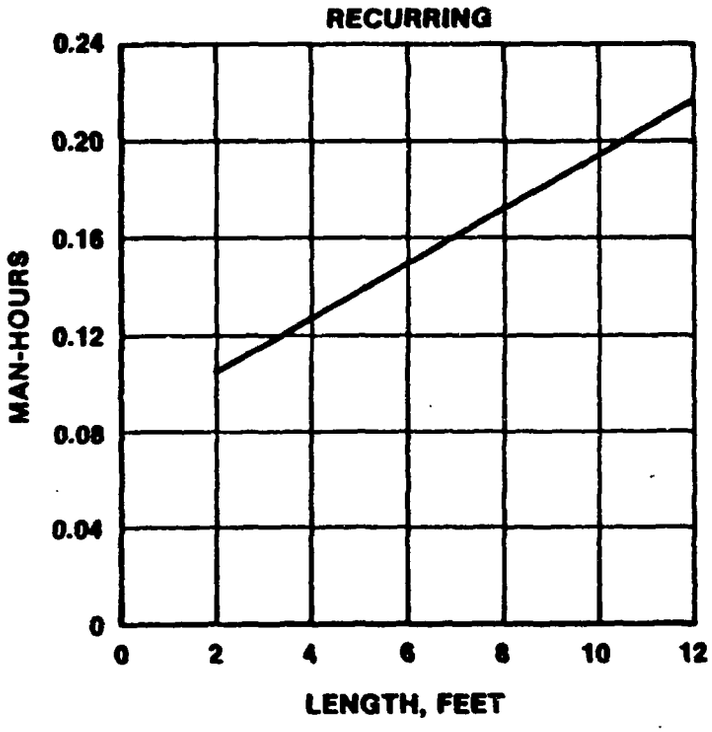


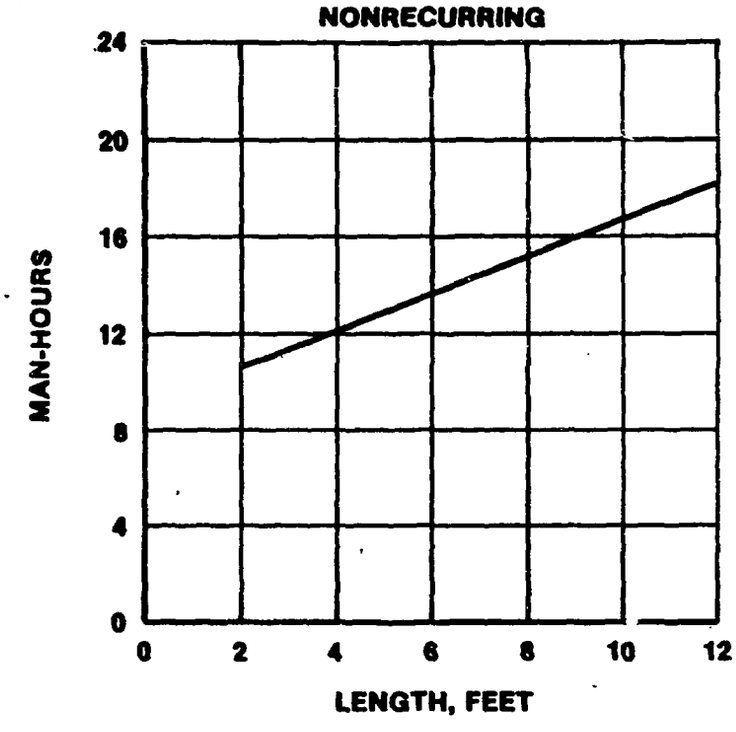




APPLICABLE DICE (A,B,D)

CED-TI&E-A-16

# TI&E
# ALUMINUM LIPPED HAT, CYLINDRICALLY CONTOURED BRAKE/ROLL

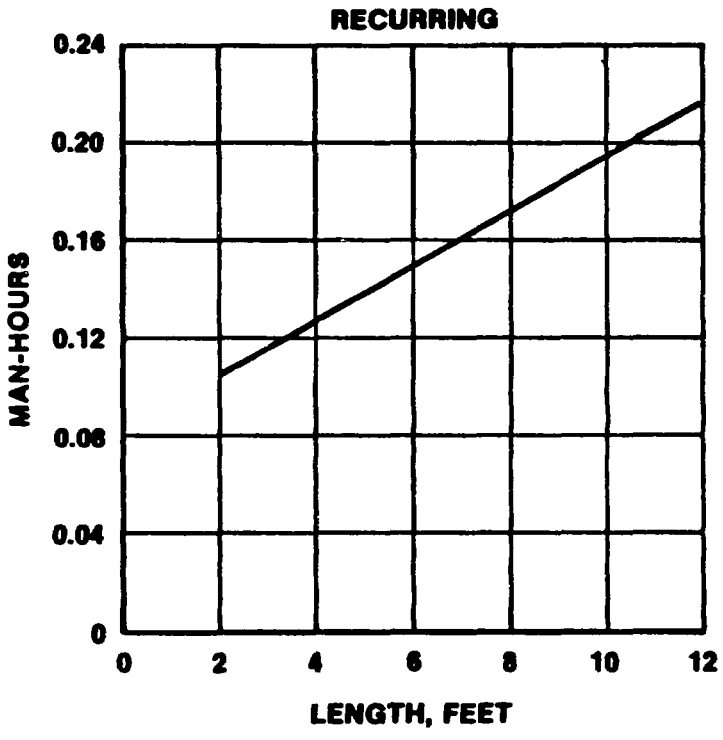


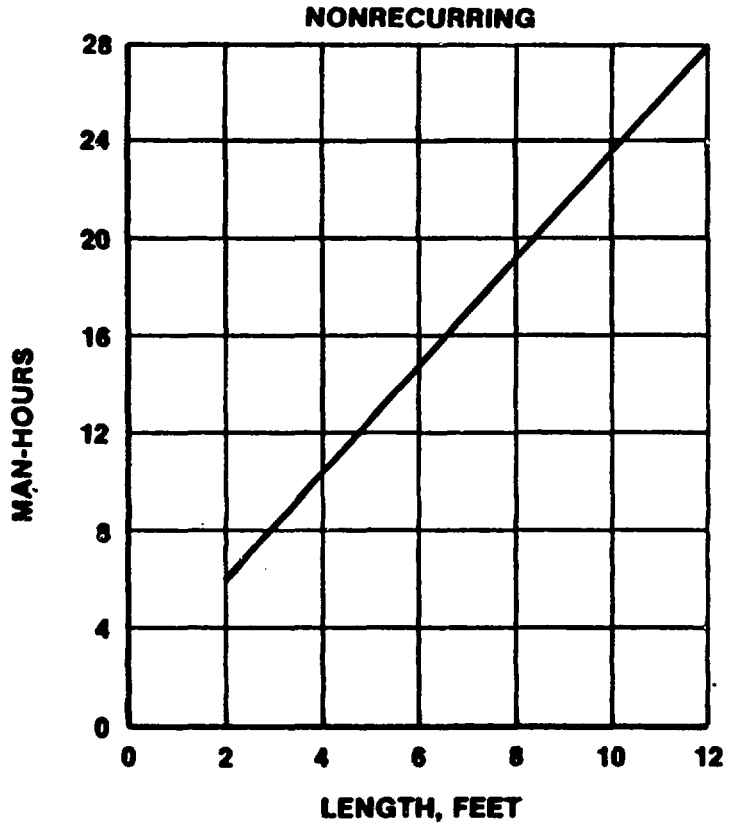




APPLICABLE DICE (A,B,E,G)

CED-TI&E-A-17

# TI&E
# ALUMINUM LIPPED HAT, NONCYLINDRICALLY CONTOURED* BRAKE/STRETCH



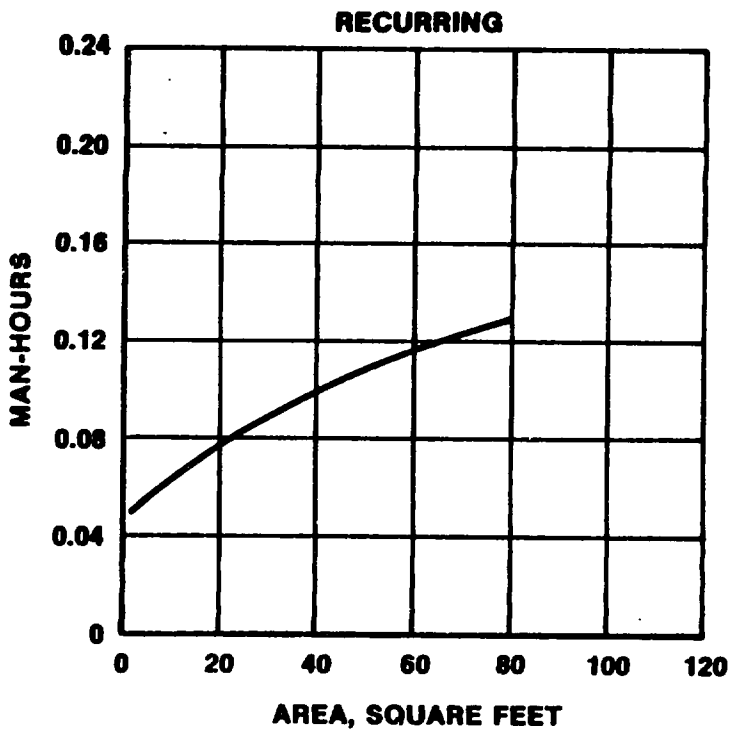



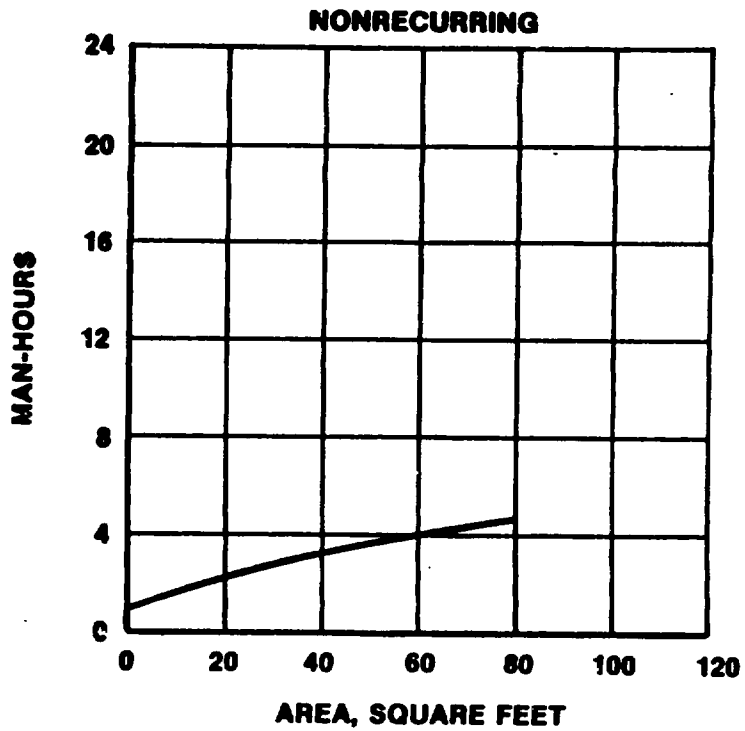

*NO REVERSE CURVATURE

APPLICABLE DICE (A,B,E)

CED-TI&E-A-18

# TI&E
# ALUMINUM FLAT SHEET
# (ROUTING APPLICABLE ONLY)



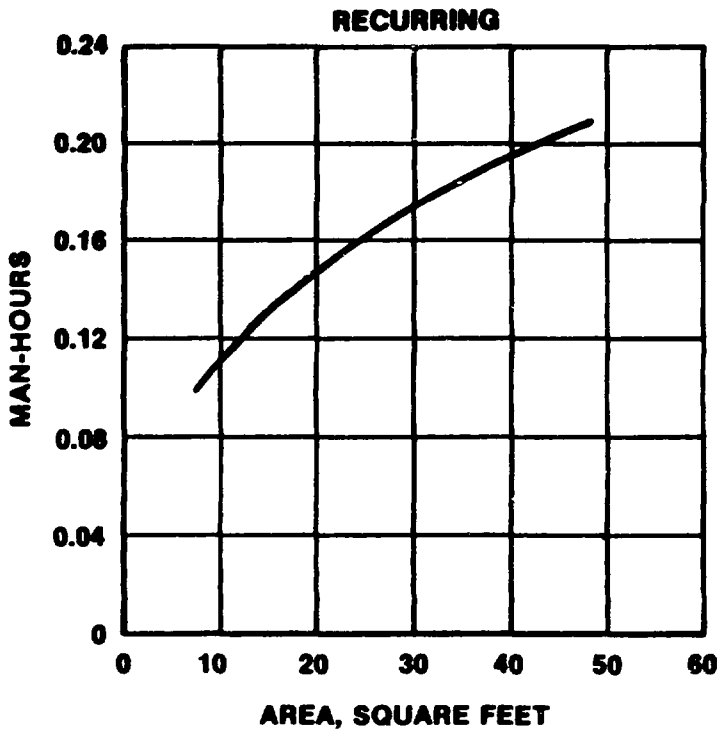

NO APPLICABLE DICE

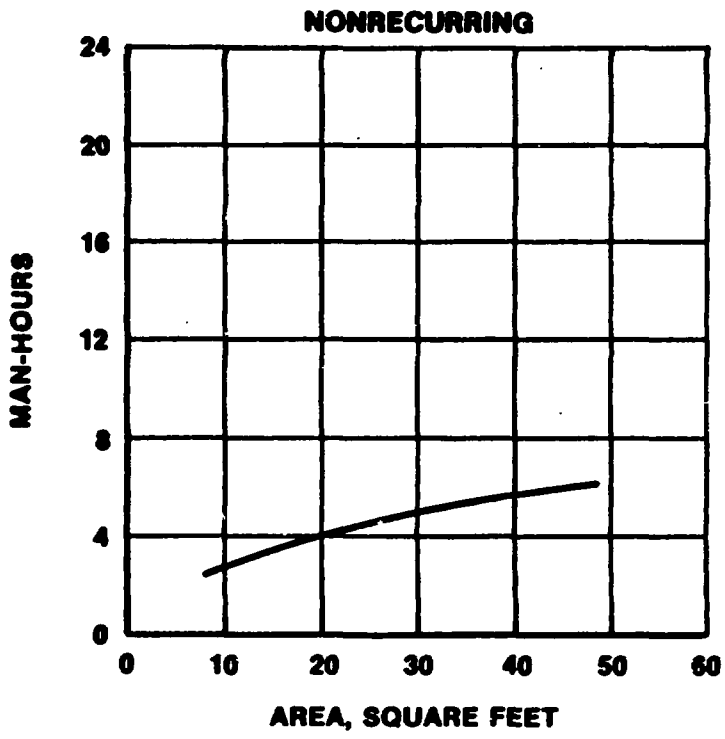
CED-TI&E-A-19



FTR450261000U
3 Jan 1983

# TI&E
# ALUMINUM CYLINDRICAL CURVATURE SKIN
# FARNHAM ROLL

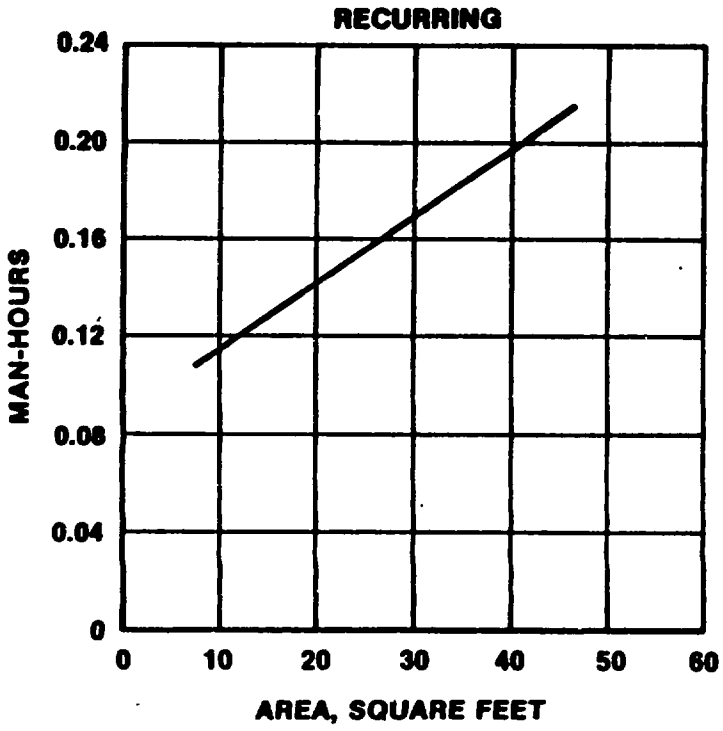


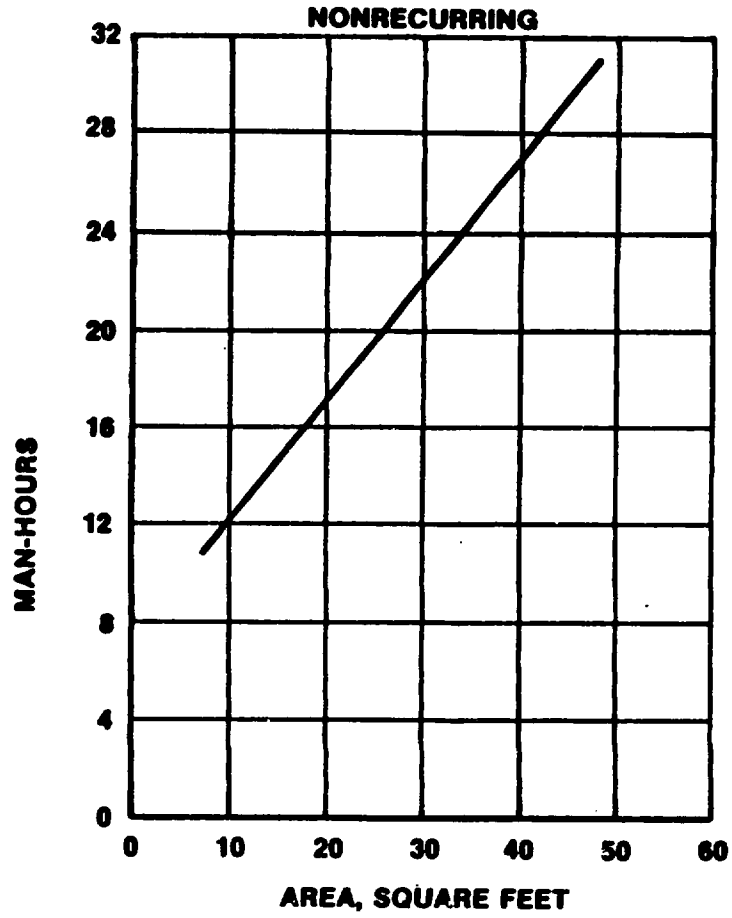




APPLICABLE DICE (D)

CED-TI&E-A-20

# TI&E
# ALUMINUM NONCYLINDRICAL CURVATURE SKIN*
# STRETCH FORM



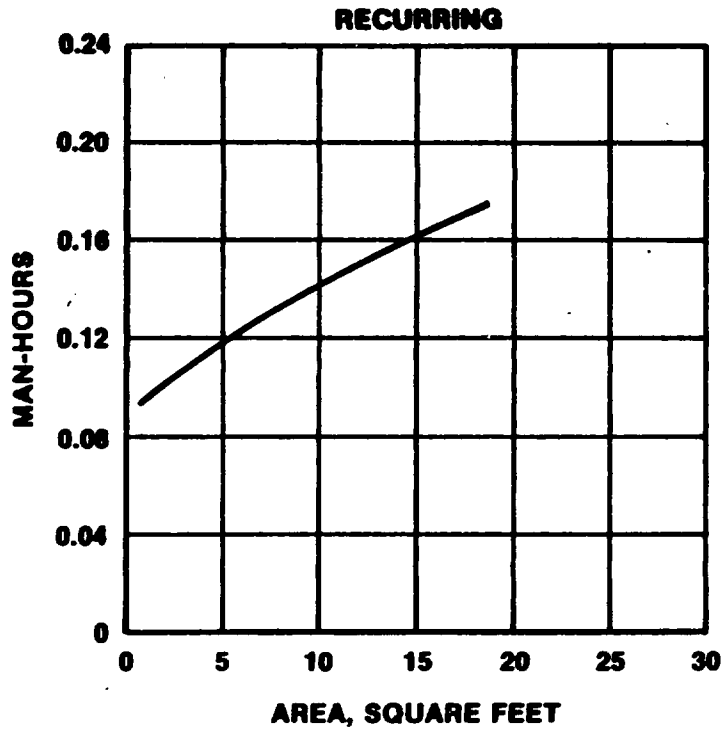



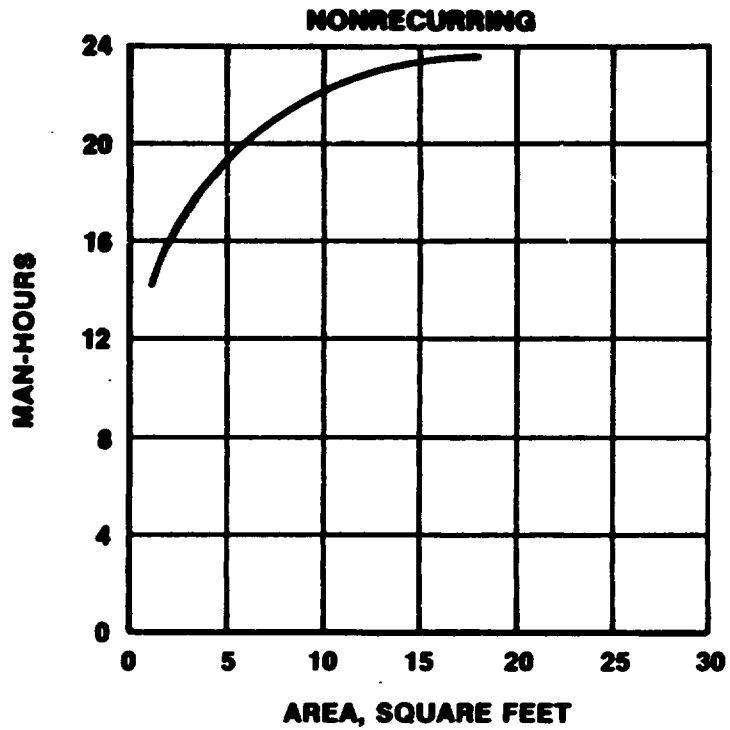

*NO REVERSE CURVATURE

APPLICABLE DICE (D)

CED-TI&E-A-21

# TI&E
# ALUMINUM FAIRING
# DROP HAMMER

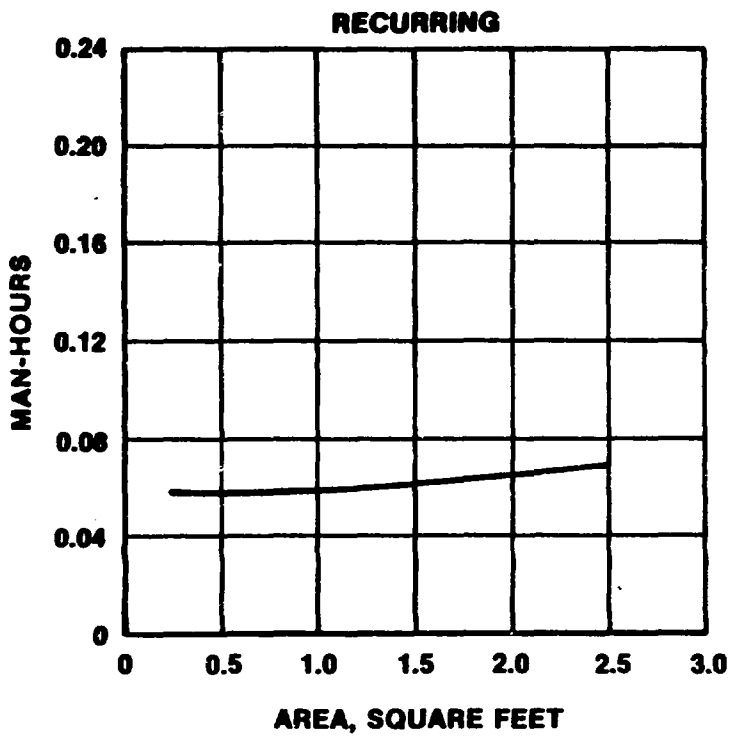


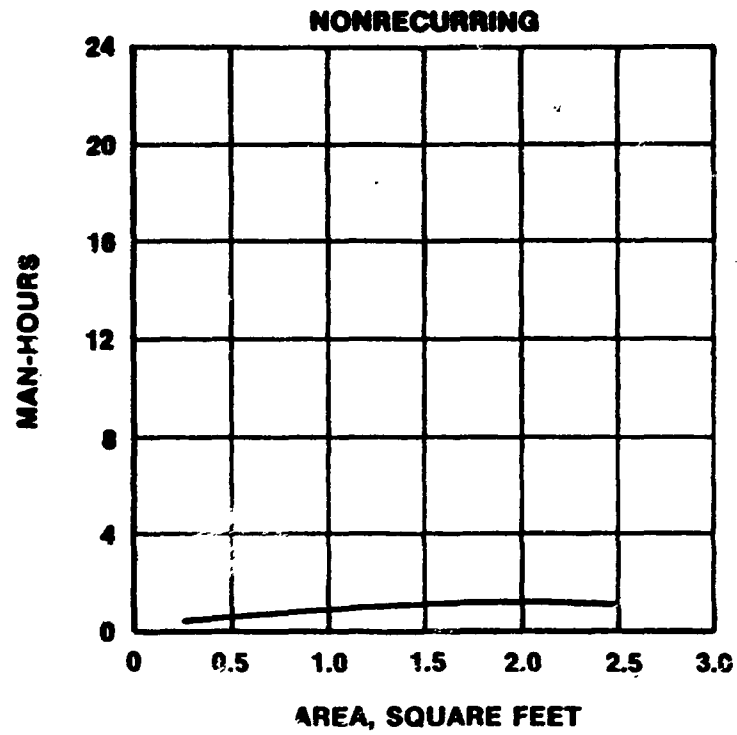




APPLICABLE DICE (D)

CED-TI&E-A-22

# TI&E
# ALUMINUM RIB
# RUBBER PRESS

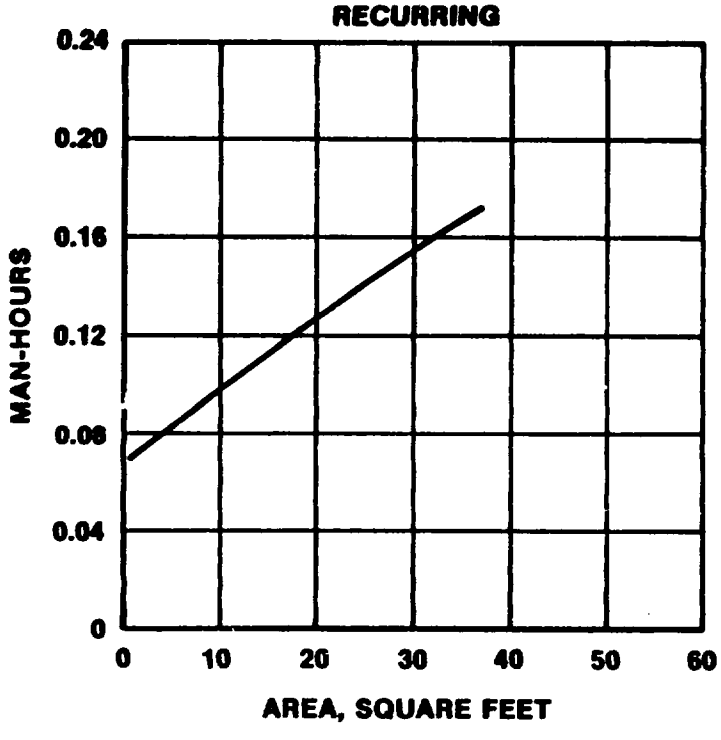


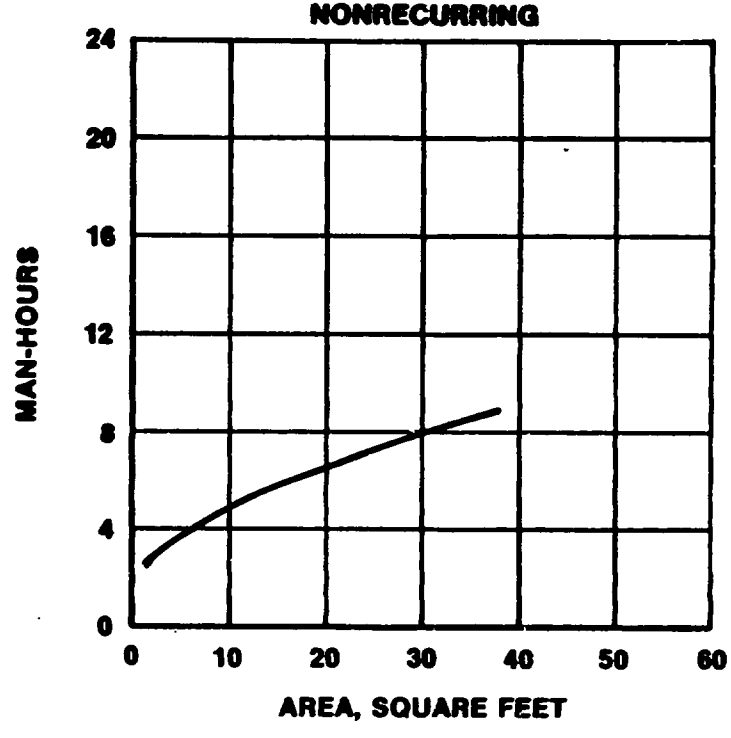




APPLICABLE DICE (A,B,D,E)

CED-TI&E-A-23

# TI&E
# ALUMINUM BEADED PANEL
# RUBBER PRESS

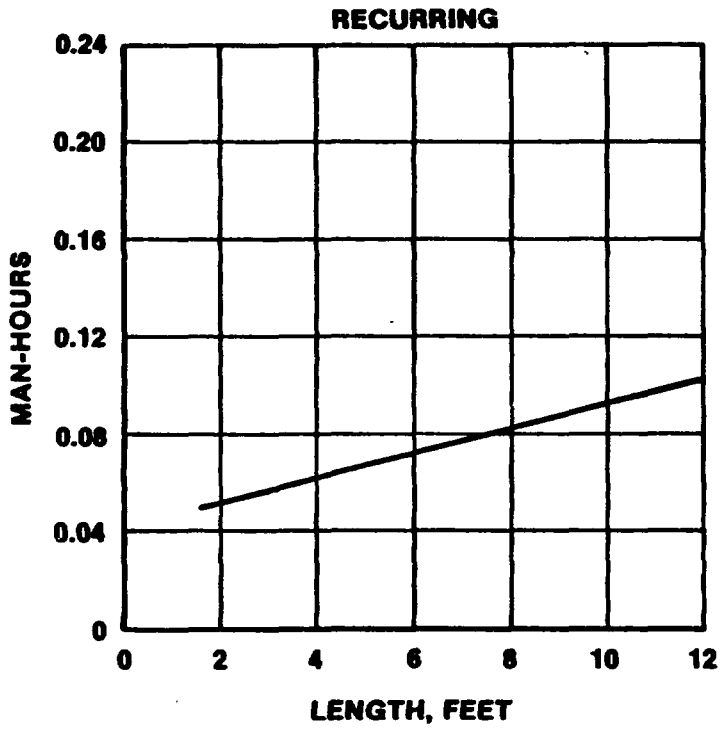


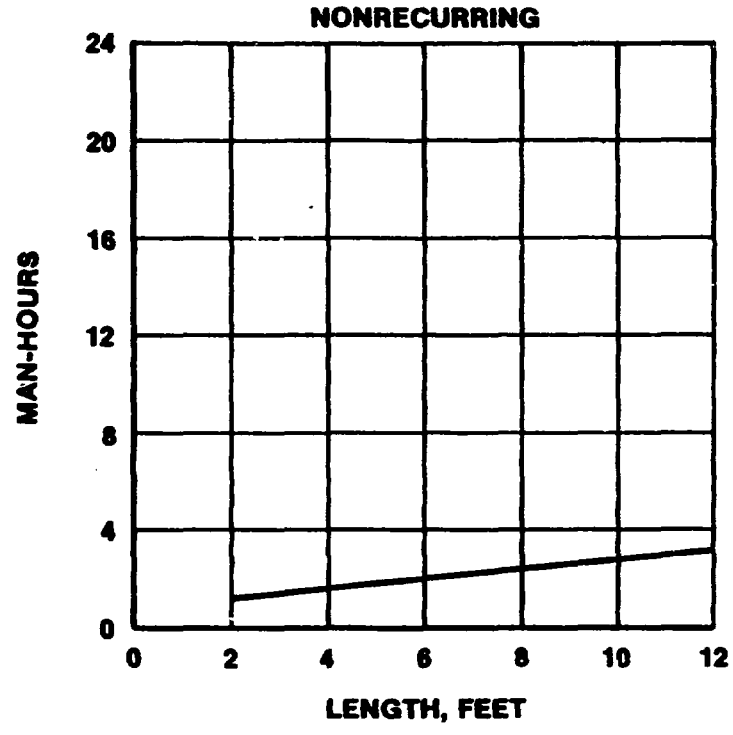




APPLICABLE DICE (D)

CED-TI&E-A-24

# TI&E
# STEEL ANGLE, STRAIGHT MEMBER
# BRAKE FORM

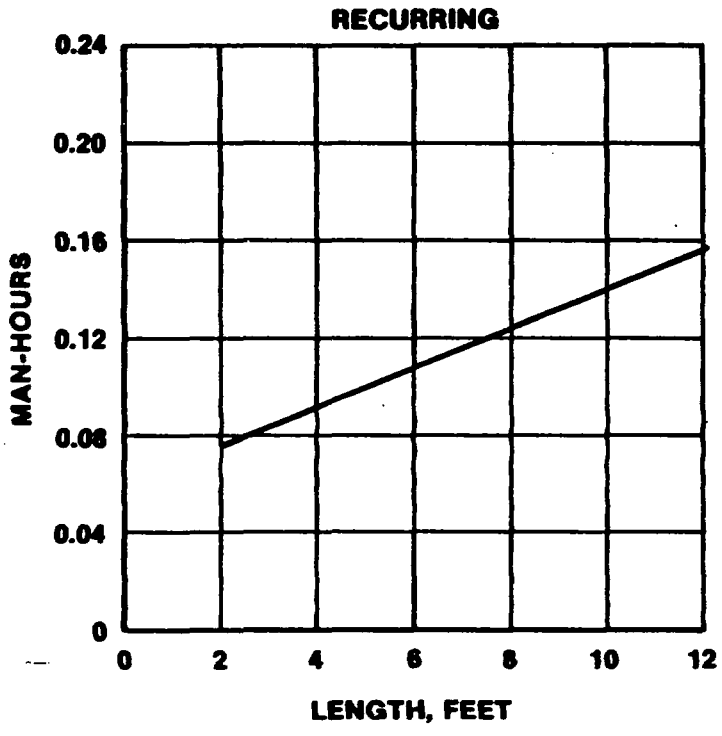


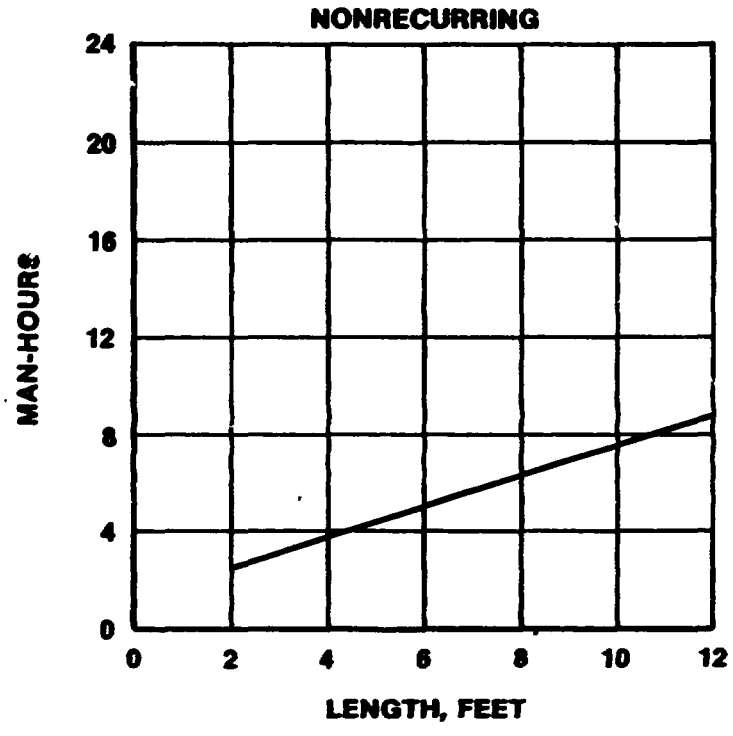




APPLICABLE DICE (A,B,D)

**CED-TI&E-S-1**

# TI&E
# STEEL ANGLE, CONTOURED MEMBER*
# RUBBER PRESS



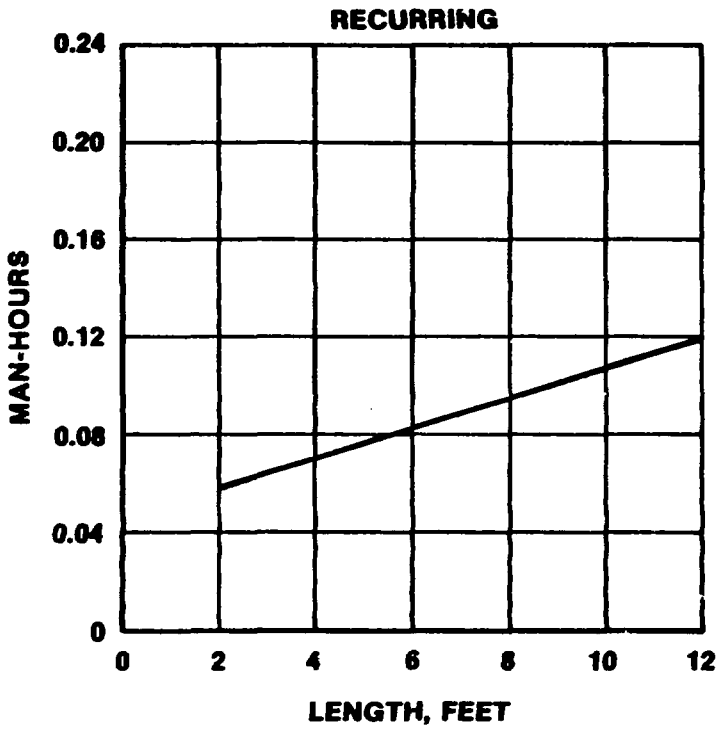



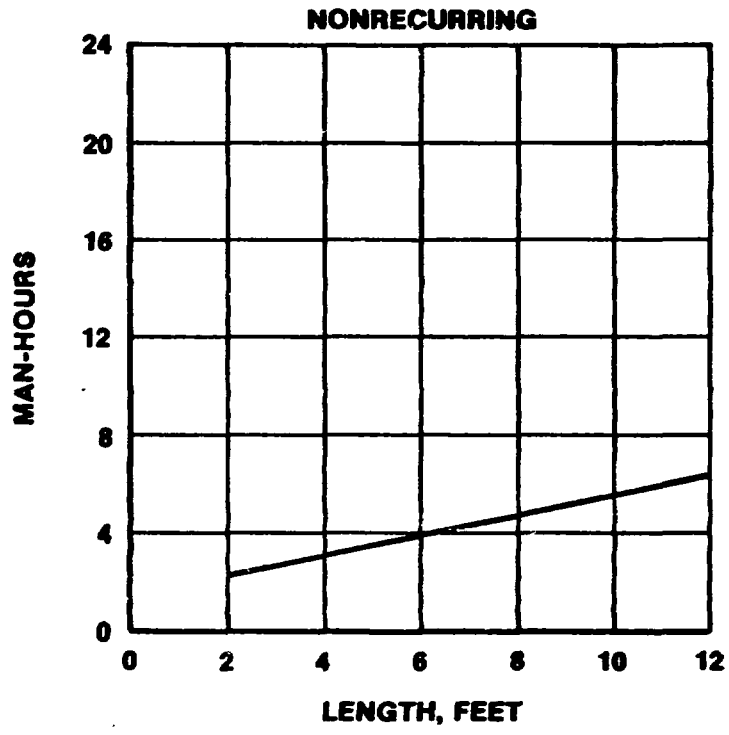

*NO REVERSE CURVATURE

APPLICABLE DICE (A,B,D,E)

**CED-TI&E-S-2**

# TI&E
# STEEL CHANNEL, STRAIGHT MEMBER
# BRAKE FORM

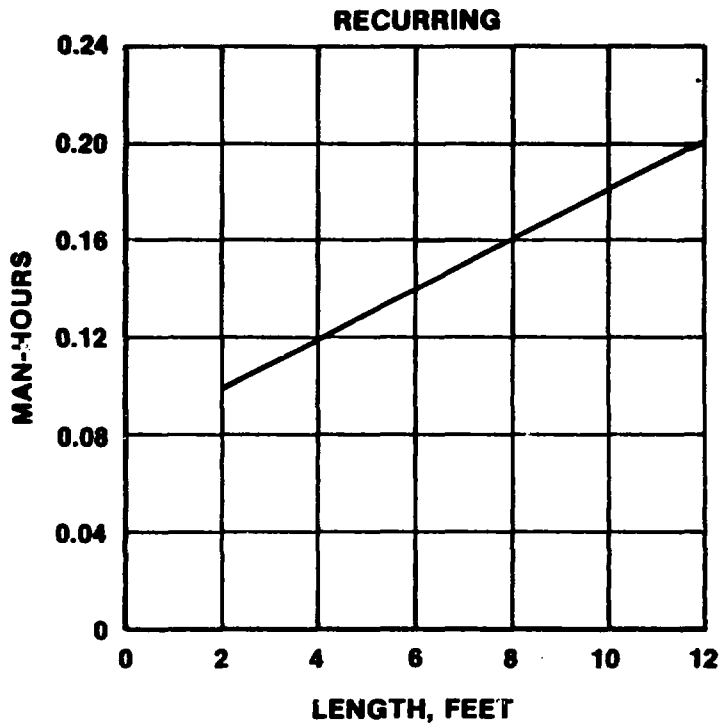


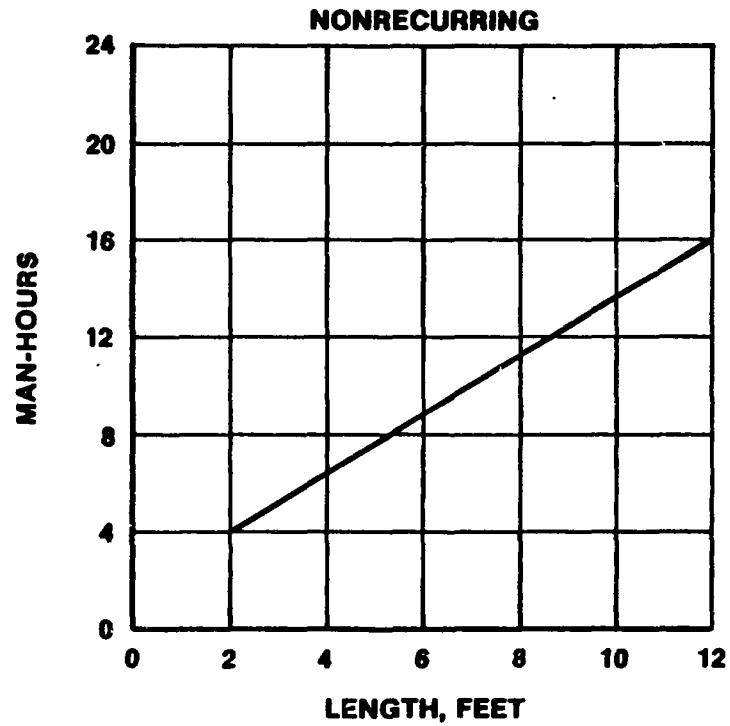




APPLICABLE DICE (A,B,D)

**CED-TI&E-S-3**

# TI&E
# STEEL CHANNEL, CONTOURED MEMBER*
# RUBBER PRESS




*NO REVERSE CURVATURE

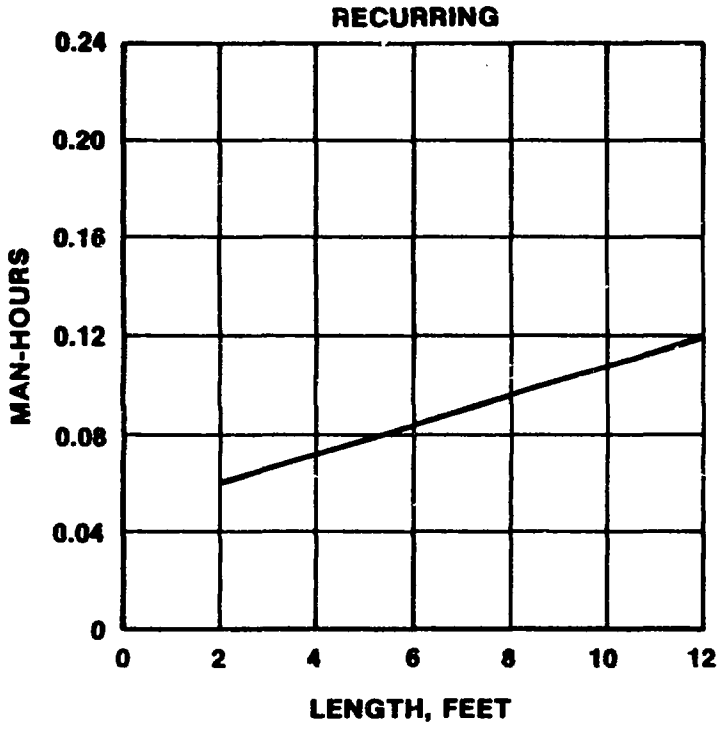
APPLICABLE DICE (A,B,D,E)

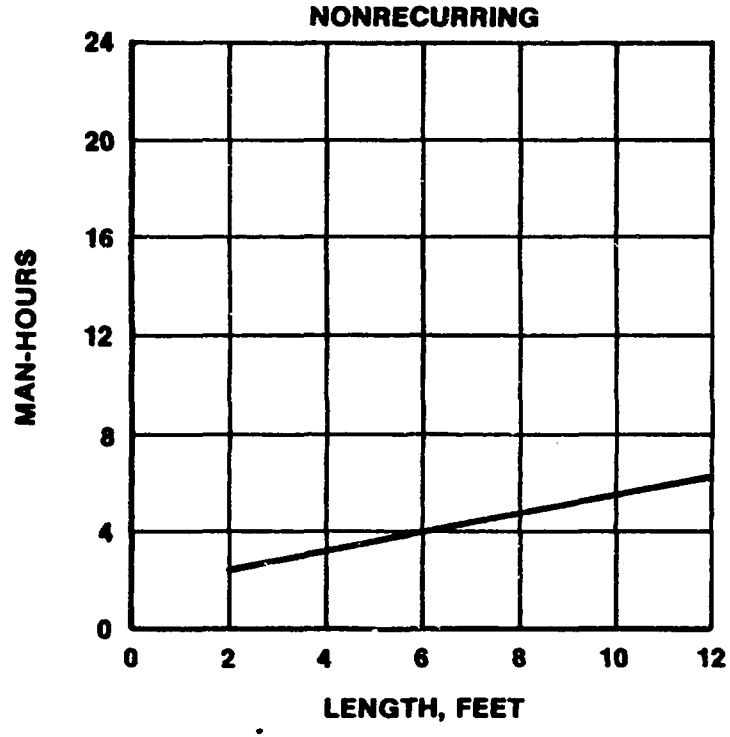
**CED-TI&E-S-4**



FTR450261000U
3 Jan 1983

# TI&E
# STEEL ZEE, STRAIGHT MEMBER
# BRAKE FORM

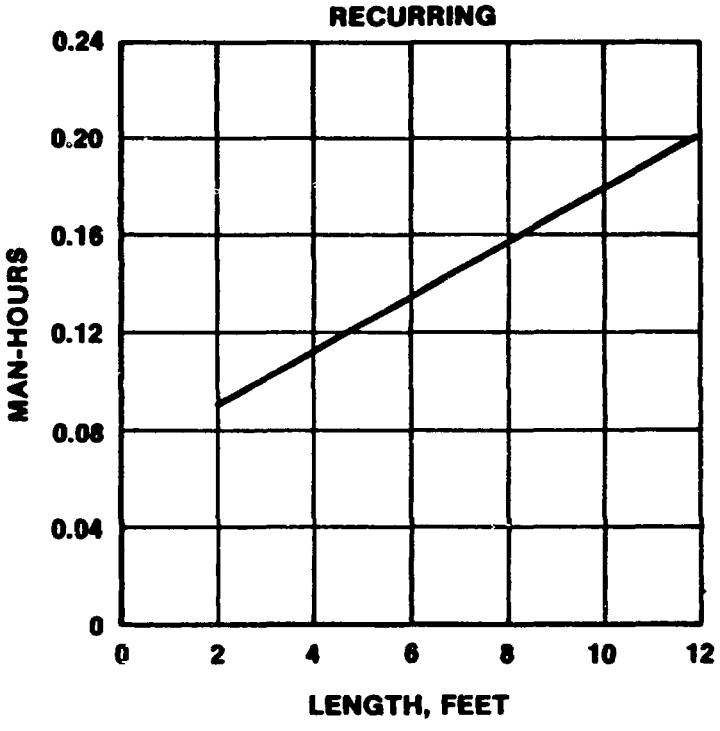


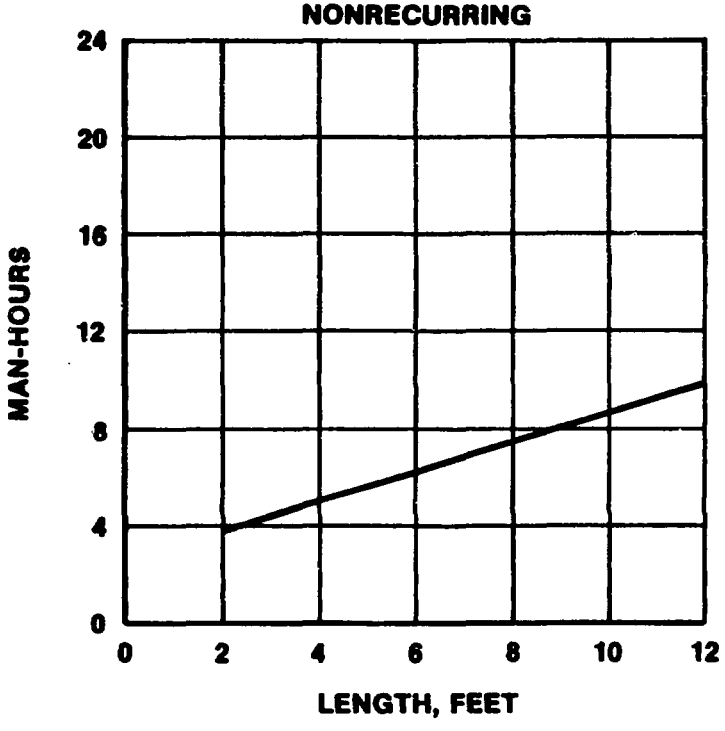




APPLICABLE DICE (A,D,E)

**CED-TI&E-S-5**

# TI&E
# STEEL ZEE, CYLINDRICALLY CONTOURED MEMBER
# BRAKE/ROLL

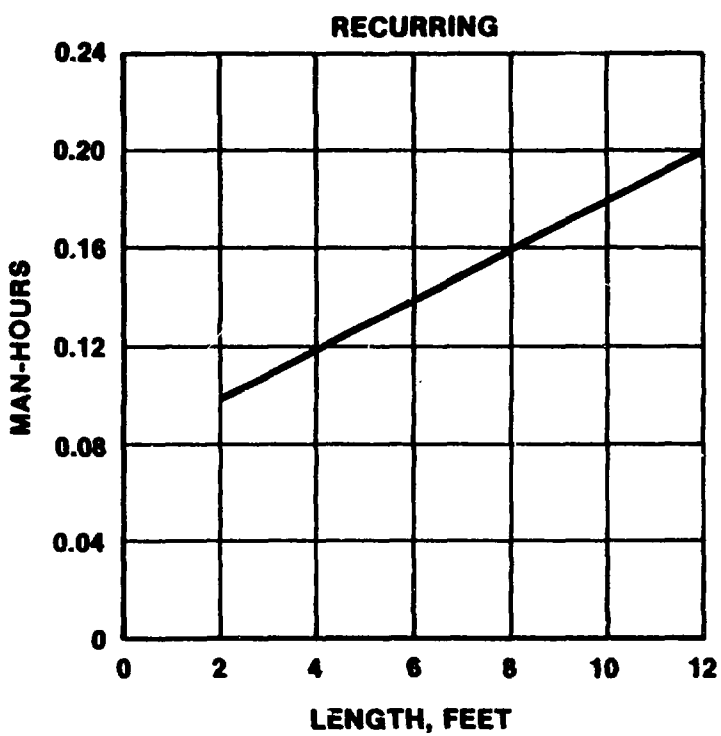


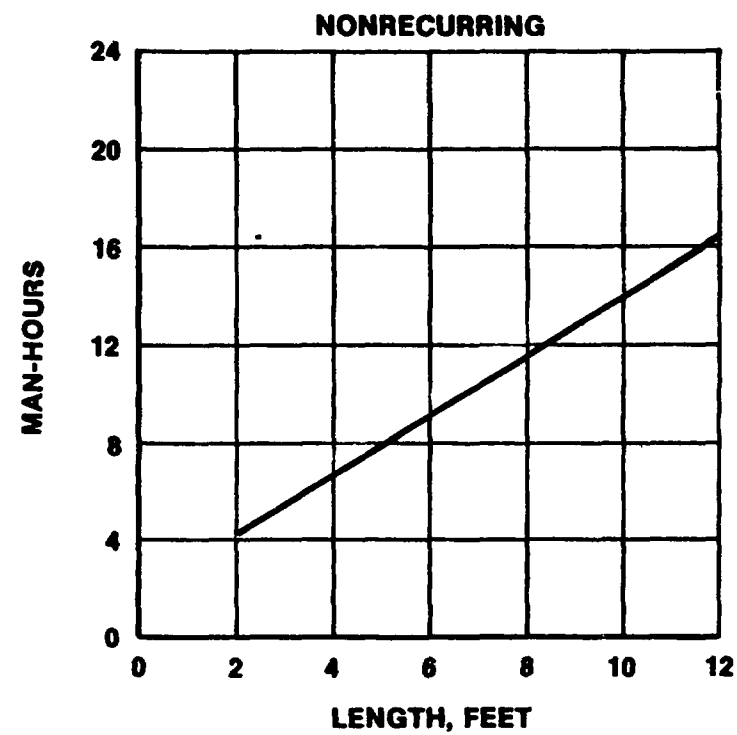




APPLICABLE DICE (A,B,E)

**CED-TI&E-S-6**

# TI&E
# STEEL ZEE, NONCYLINDRICALLY CONTOURED MEMBER*
# RUBBER PRESS




*NO REVERSE CURVATURE

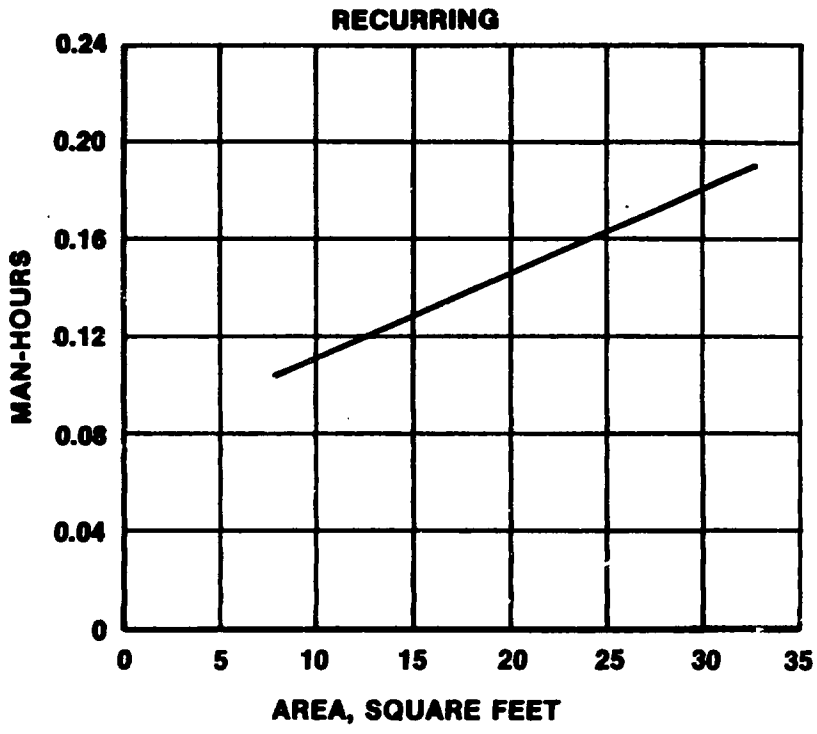
APPLICABLE DICE (A,B,D,E)

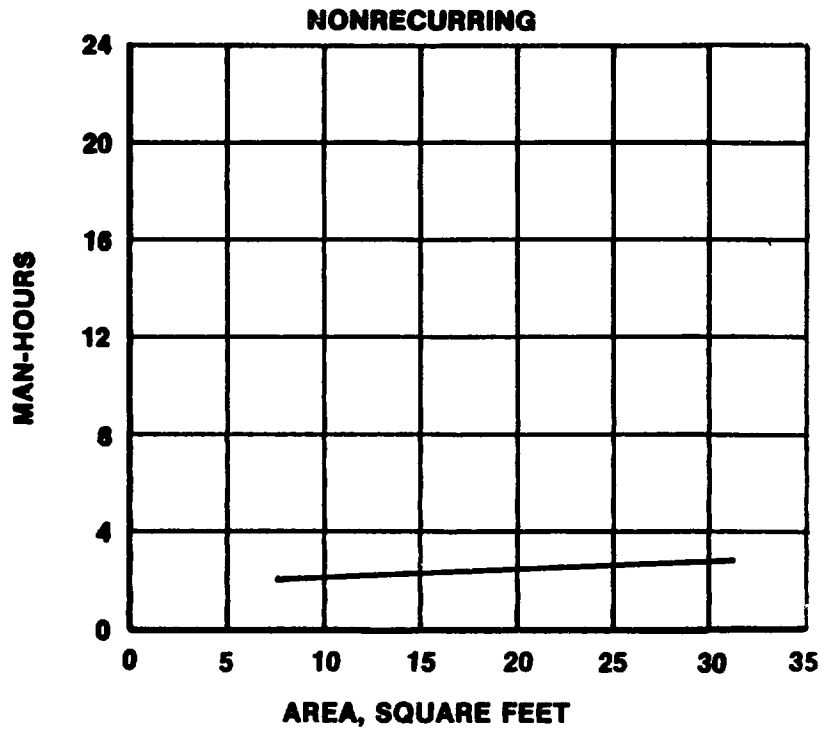
**CED-TI&E-S-7**



FTR450261000U
3 Jan 1983

# TI&E
# STEEL CYLINDRICAL CURVATURE SKIN
# FARNHAM ROLL

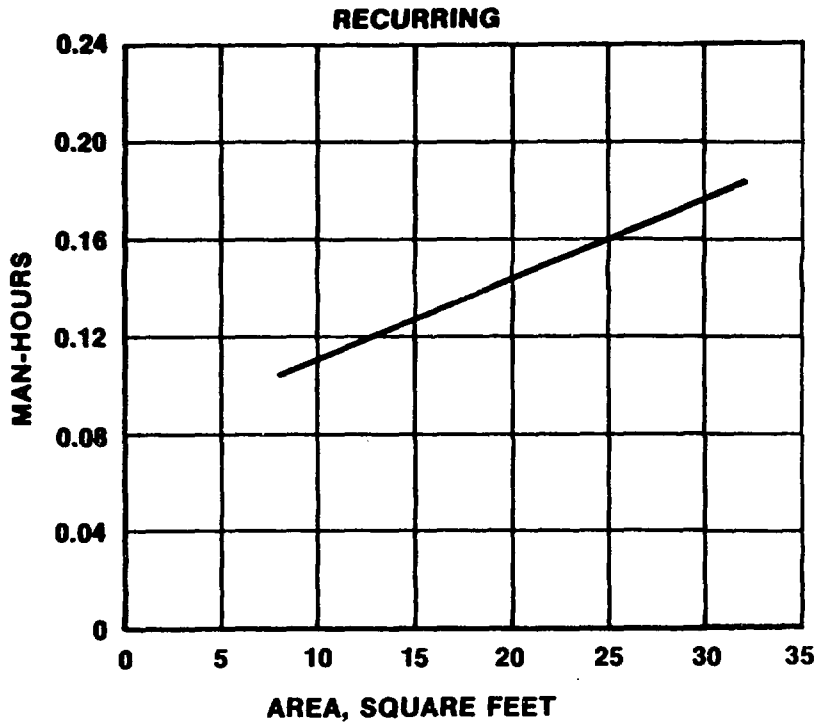


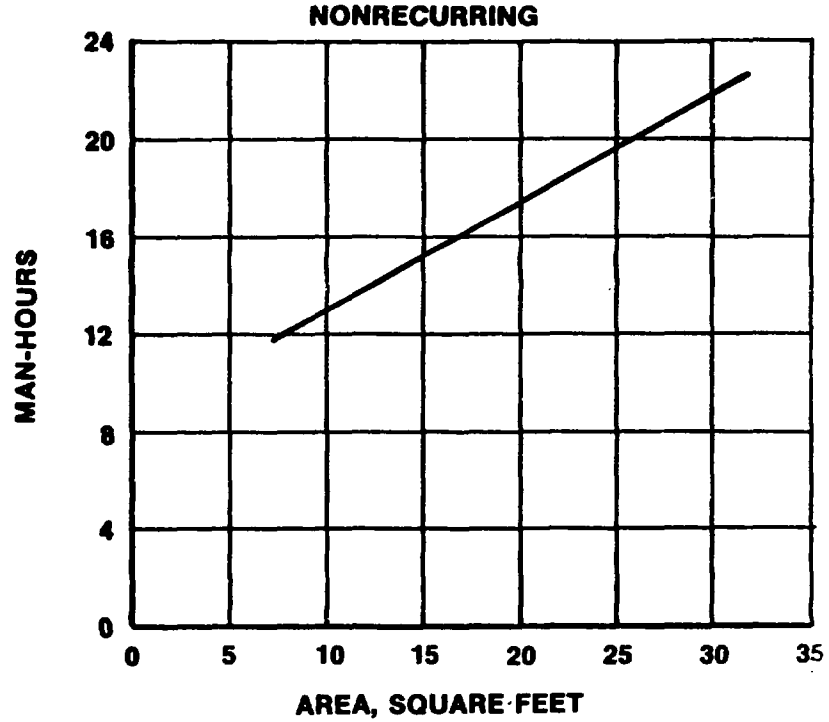




APPLICABLE DICE (D,E)

**CED-TI&E-S-8**

# TI&E
# STEEL NONCYLINDRICAL CURVATURE SKIN*
# STRETCH FORM




*NO REVERSE CURVATURE

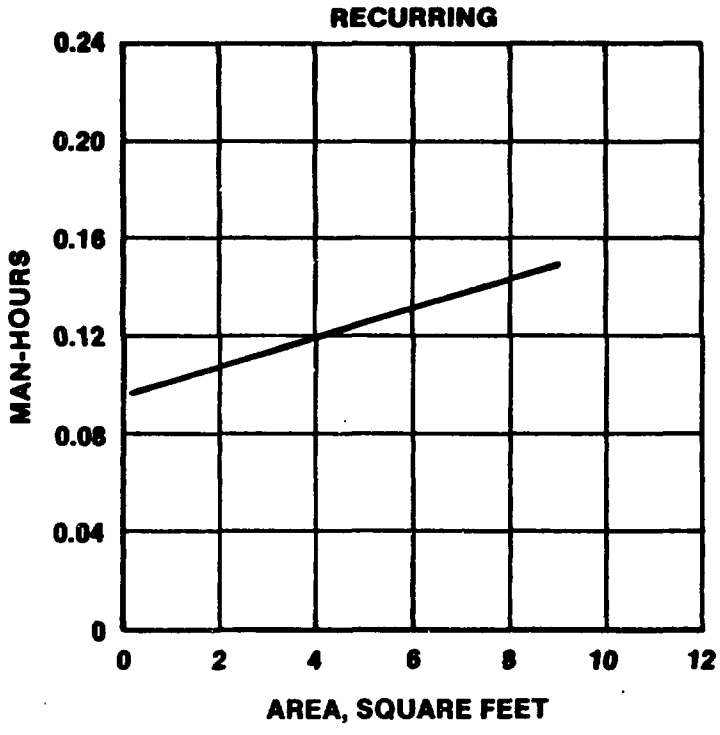
APPLICABLE DICE (D,E)

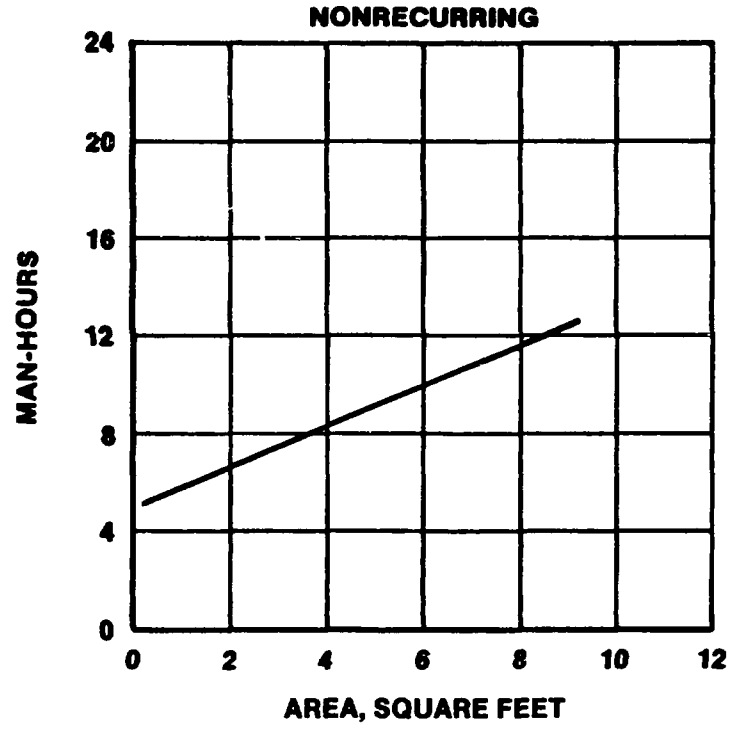
**CED-TI&E-S-9**



FTR450261000U
3 Jan 1983

# TI&E
# STEEL FRAME
# RUBBER PRESS



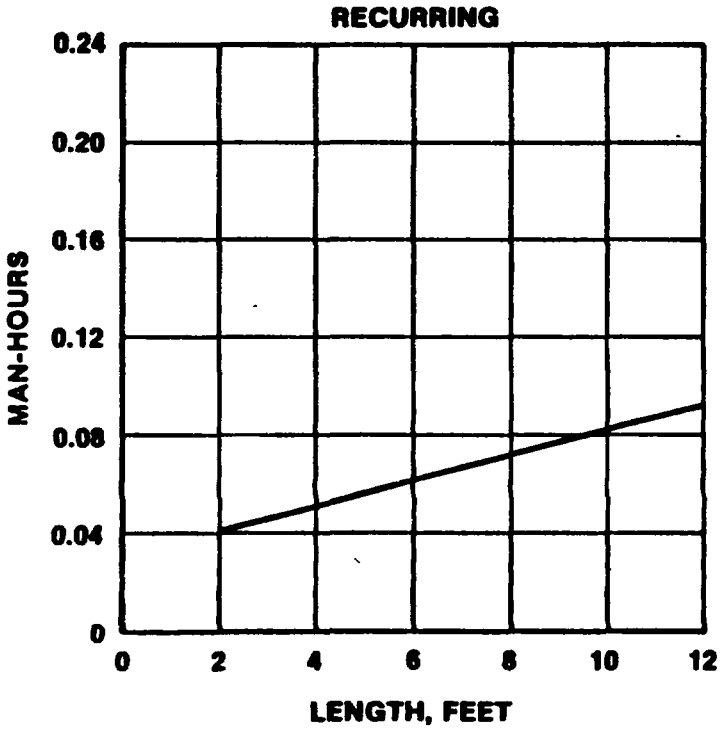

APPLICABLE DICE (A,B,D,E)

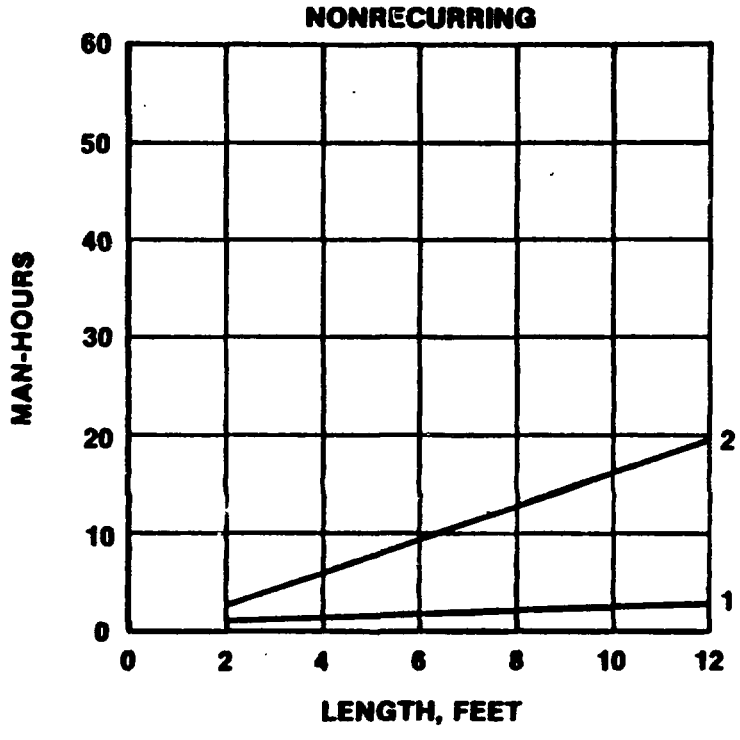
**CED-TI&E-S-10**



FTR450261000U
3 Jan 1983

# TI&E
# TITANIUM ANGLE, STRAIGHT MEMBER
# BRAKE FORM OR PREFORM/HOT SIZE




APPLICABLE DICE (A,B,D)

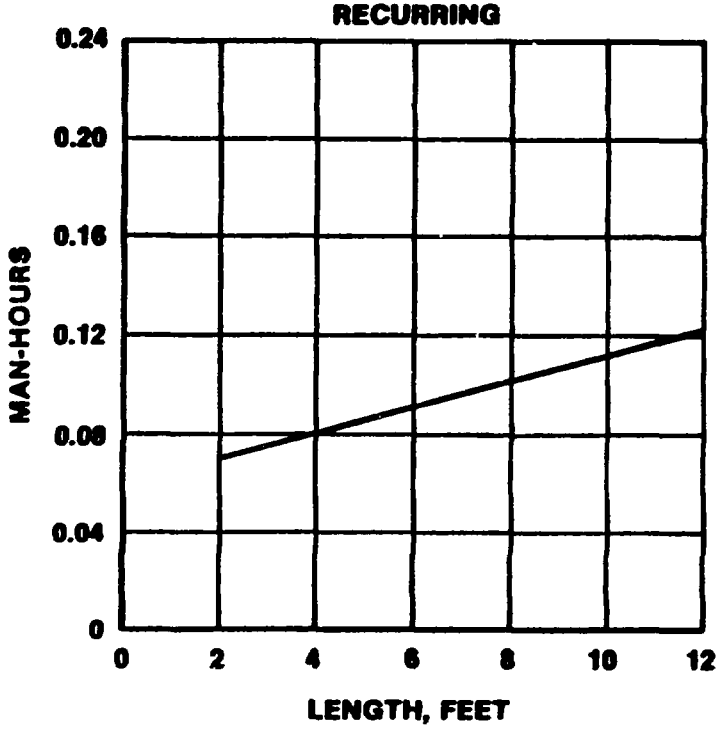
1. ROOM TEMPERATURE BRAKE FORMED, MINIMUM BEND RADIUS = 5t.
2. PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t.

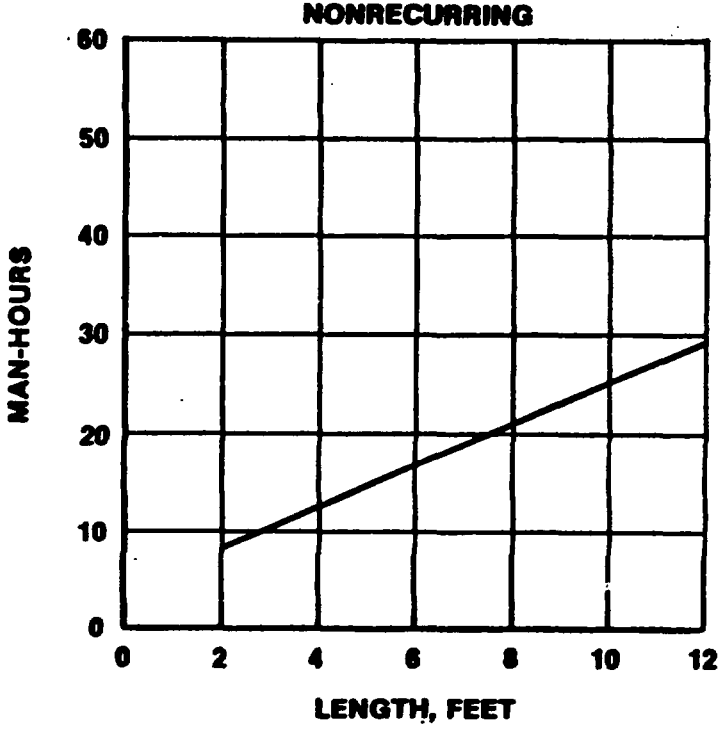
**CED-TI&E-T-1**



FTR450261000U
3 Jan 1983

# TI&E
# TITANIUM ANGLE, CONTOURED MEMBER*
# PREFORM/HOT SIZE




*NO REVERSE CURVATURE

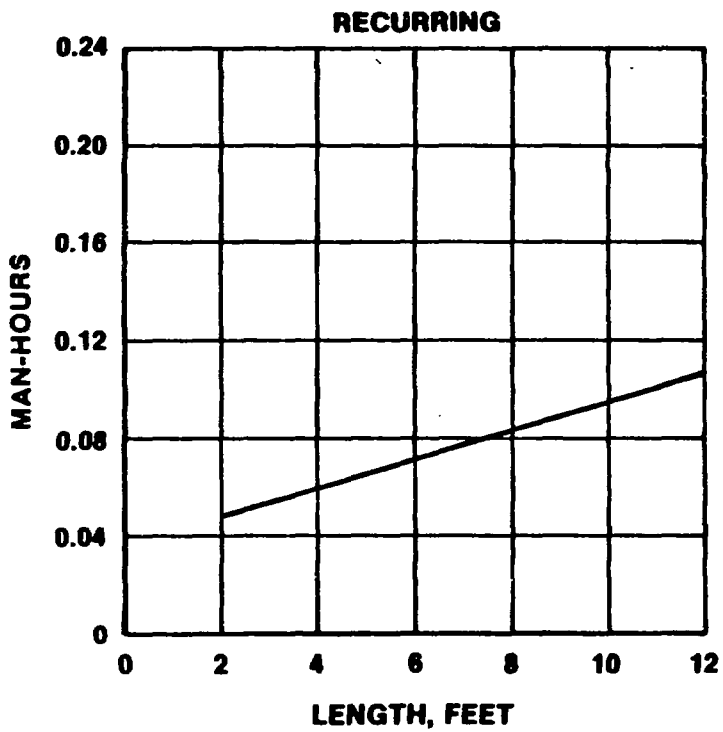
APPLICABLE DICE (A,B,D,E)

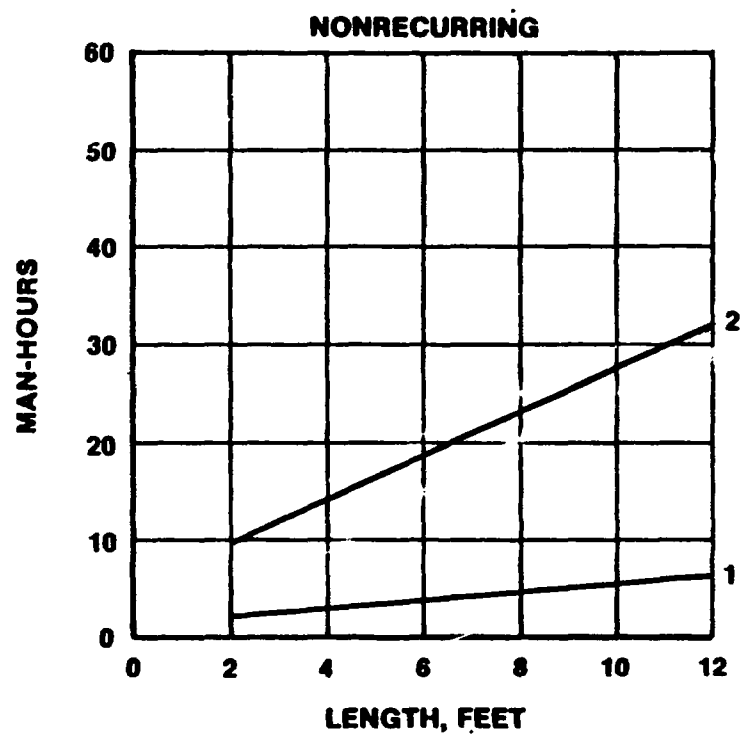
**CED-TI&E-T-2**



FTR450261000U
3 Jan 1983

# TI&E
# TITANIUM CHANNEL, STRAIGHT MEMBER
# BRAKE FORM OR PREFORM/HOT SIZE



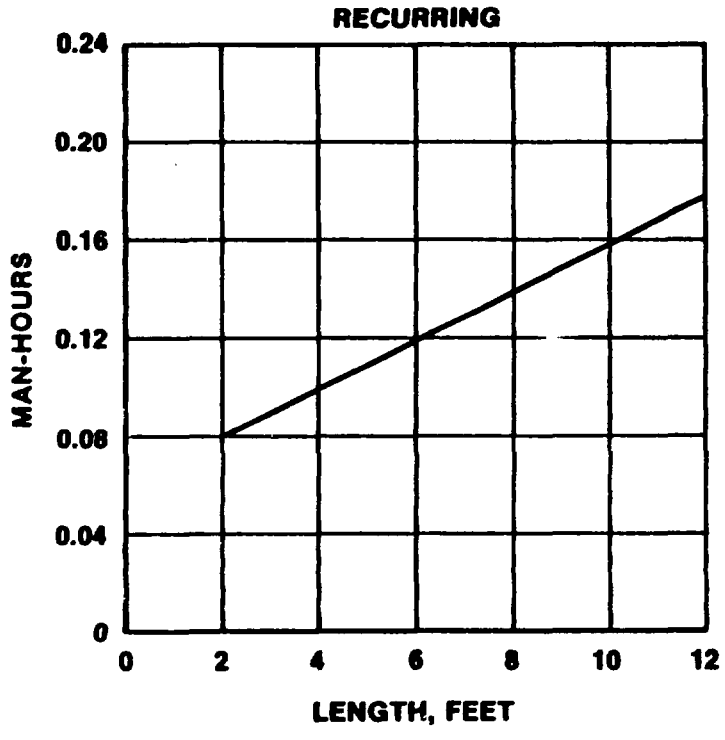



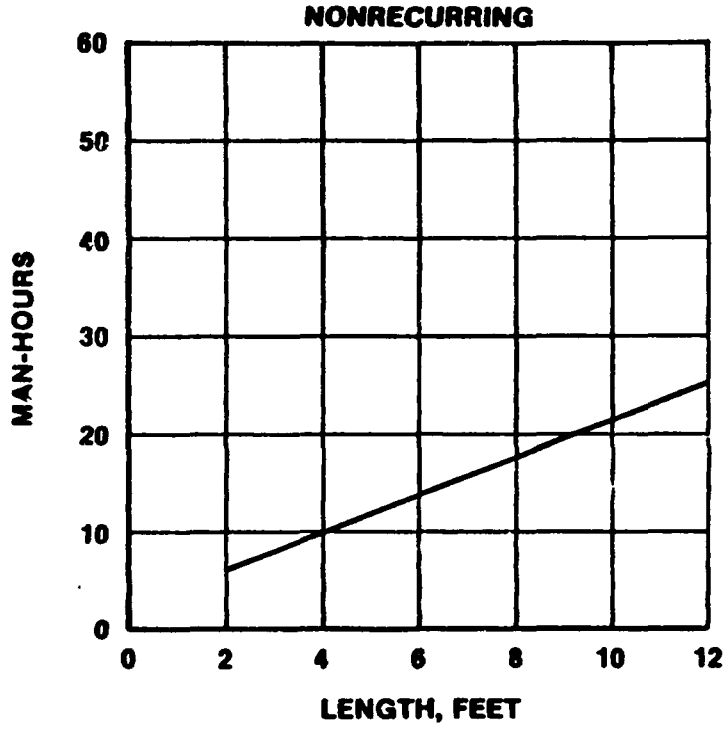

APPLICABLE DICE (A,B,D,E)

1. ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t.
2. PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t.

**CED-TI&E-T-3**

# TI&E
# TITANIUM CHANNEL, CONTOURED MEMBER*
# BRAKE/HOT STRETCH




*NO REVERSE CURVATURE

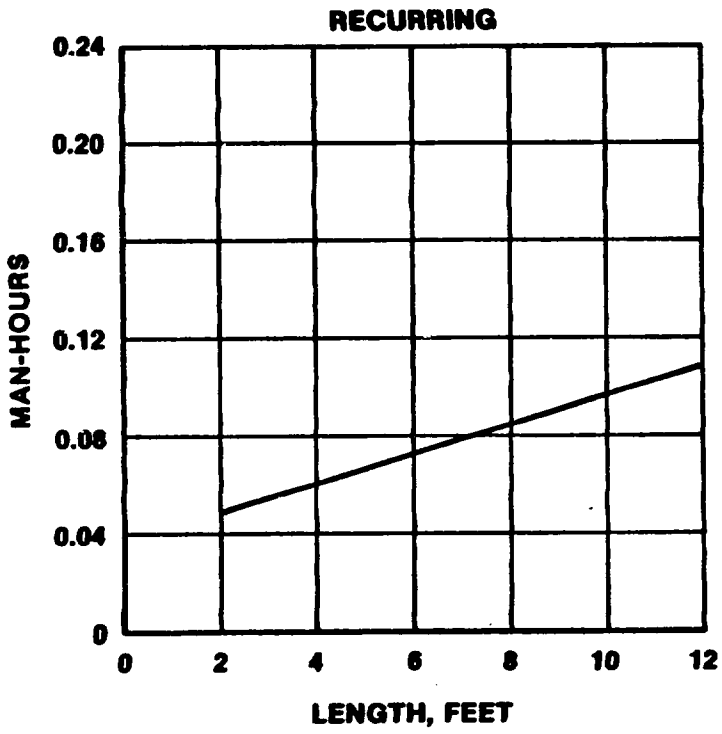
APPLICABLE DICE (A,B,D)

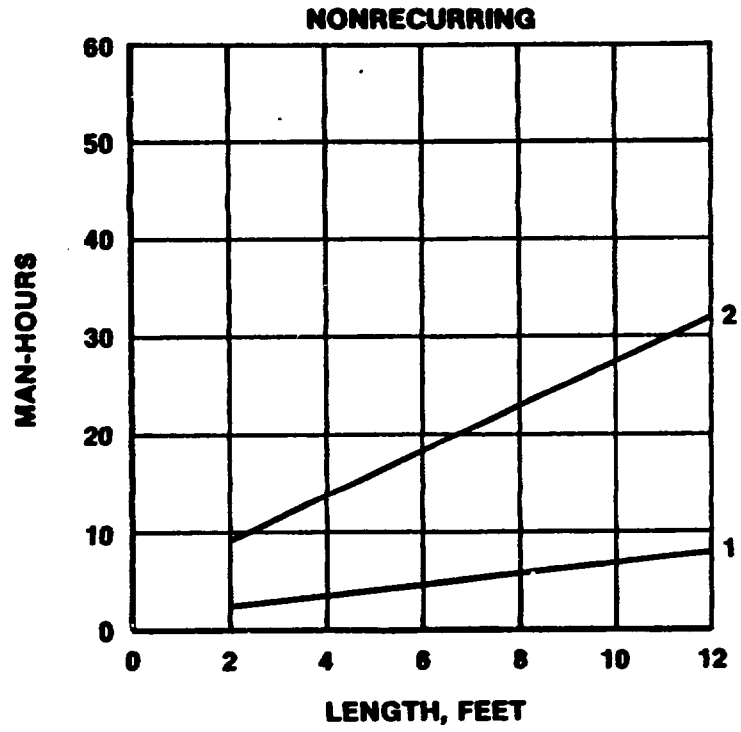
**CED-TI&E-T-4**



FTR450261000U
3 Jan 1983

# TI&E
# TITANIUM ZEE, STRAIGHT MEMBER
# BRAKE FORM OR PREFORM/HOT SIZE




APPLICABLE DICE (A,B,D,E)

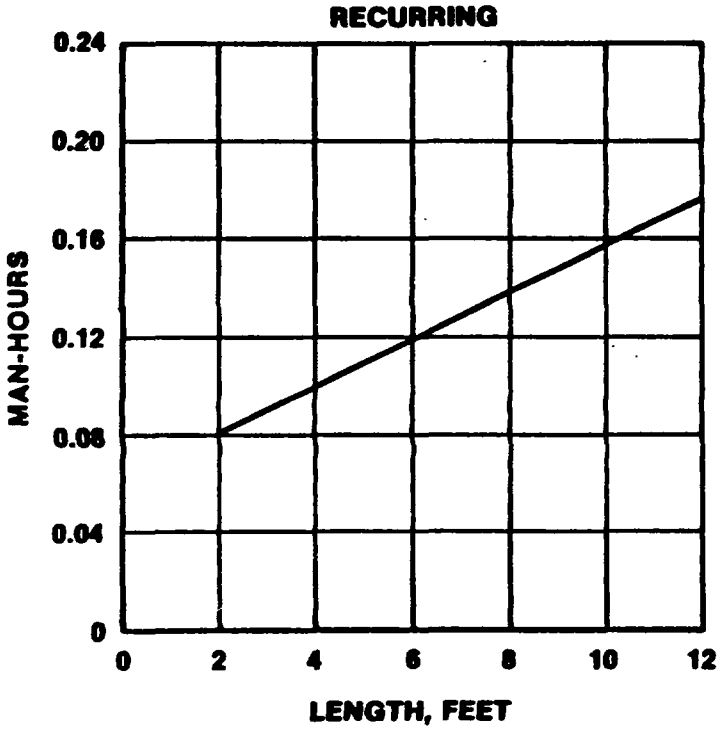
1. ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t.
2. PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t.

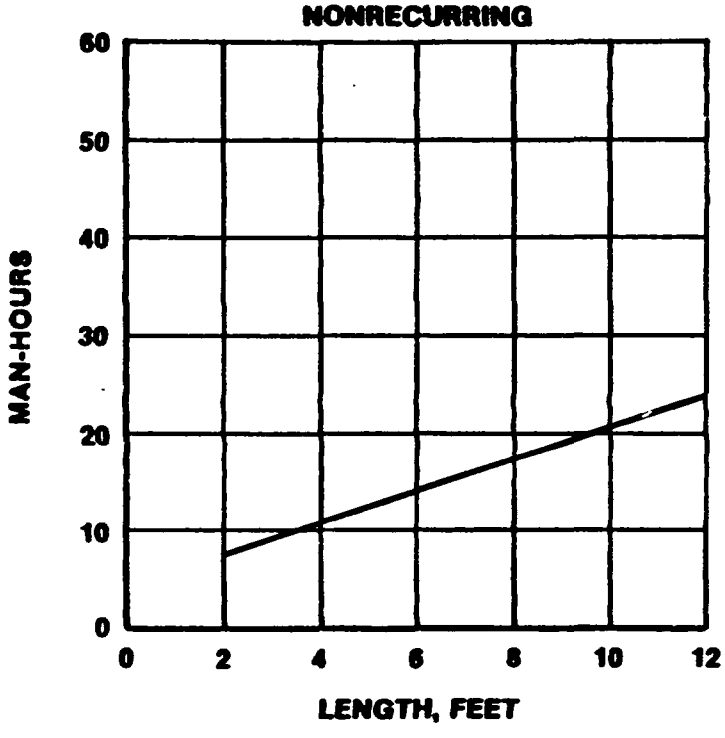
CED-TI&E-T-5



FTR450261000U
3 Jan 1983

# TI&E
# TITANIUM ZEE, CONTOURED MEMBER*
# BRAKE/STRETCH



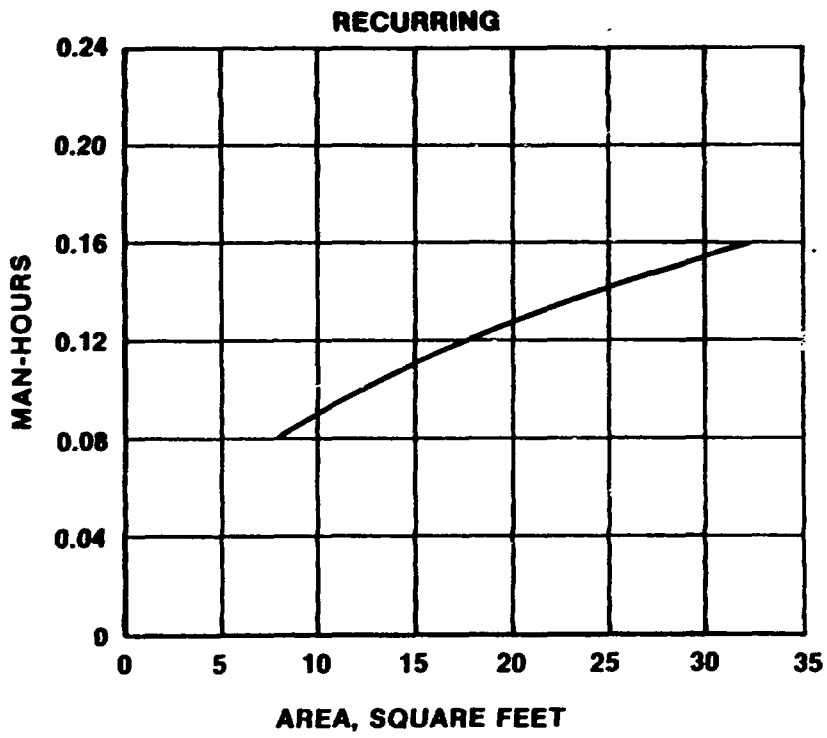



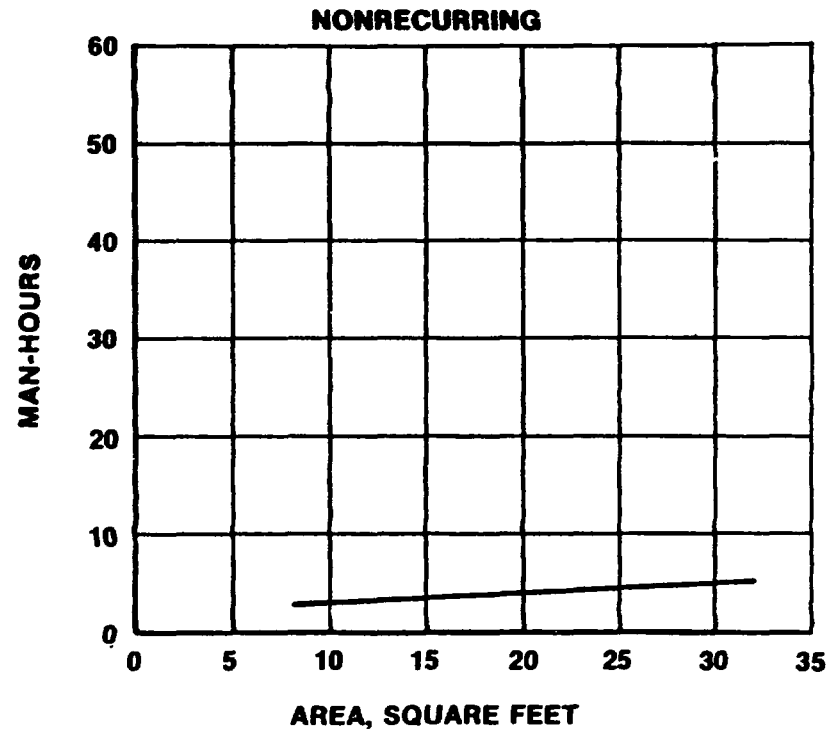

*NO REVERSE CURVATURE

APPLICABLE DICE (A,B,E)

**CED-TI&E-T-6**

# TI&E
# TITANIUM CYLINDRICAL CURVATURE SKIN
# FARNHAM ROLL



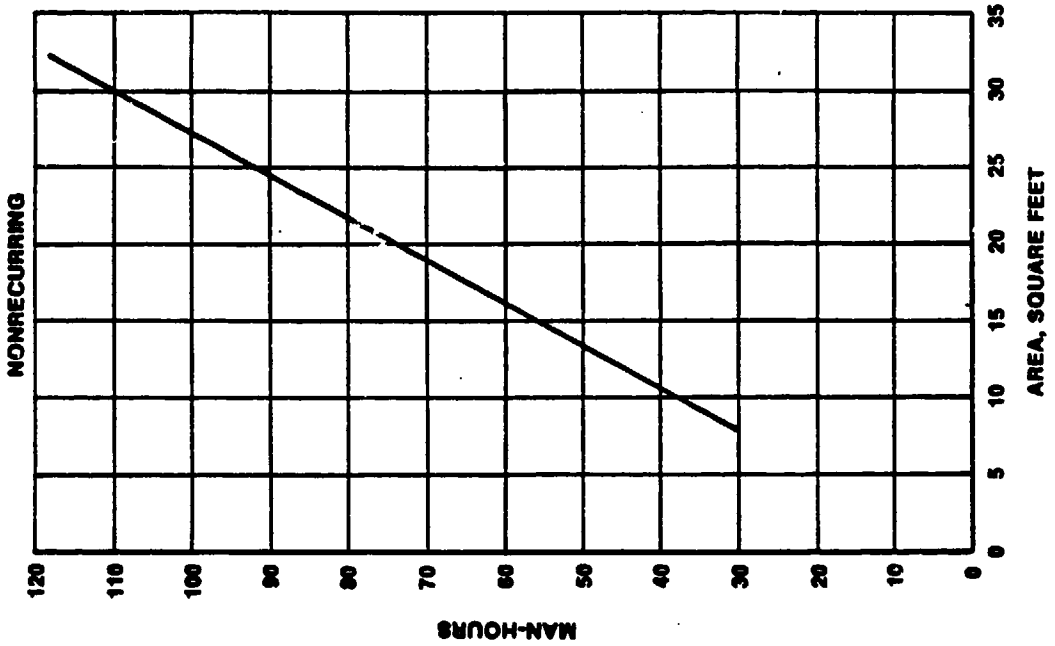

APPLICABLE DICE (D,E)

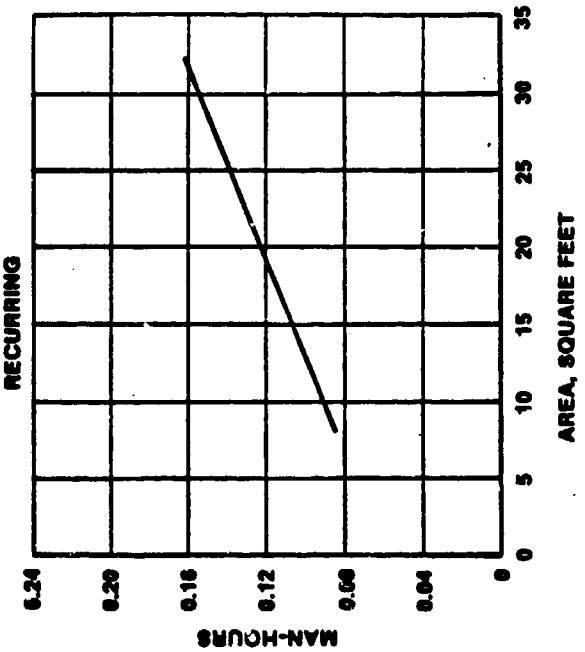
CED-TI&E-T-7



FTR450261000U
3 Jan 1983

# TI&E
# TITANIUM NONCYLINDRICAL CURVATURE SKIN* CREEP FORM



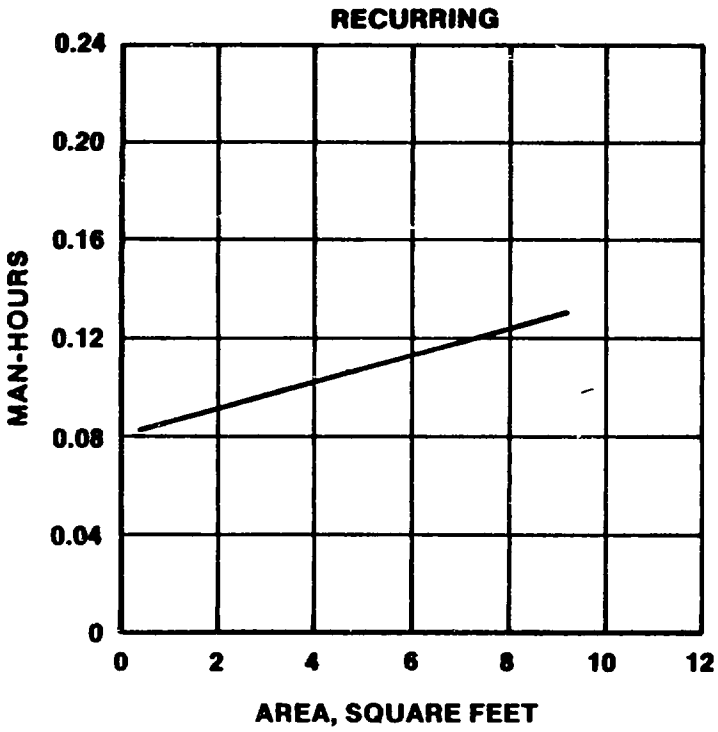



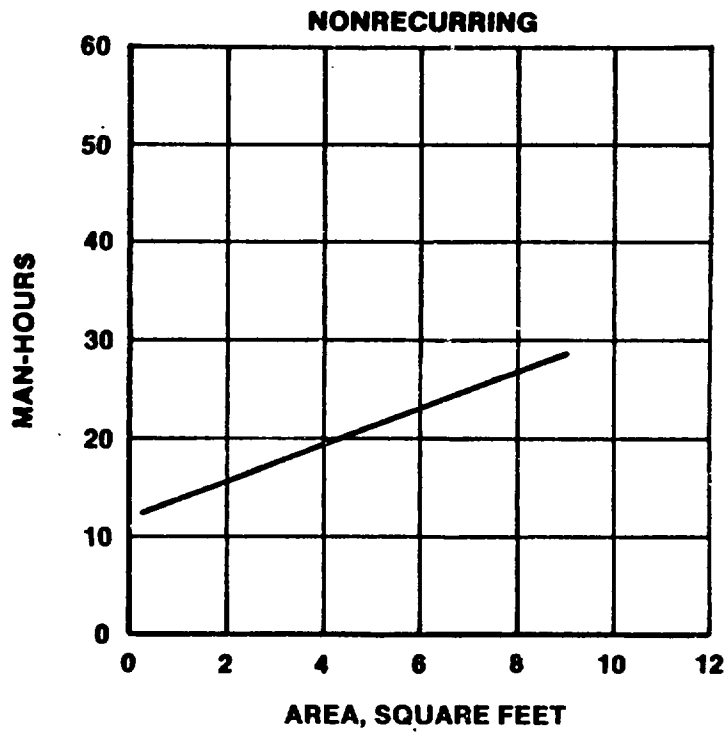

*NO REVERSE CURVATURE

APPLICABLE DICE (D,E)

CED-TI&E-T-8

# TI&E
# TITANIUM FRAME
# HOT PRESS




APPLICABLE DICE (A,B,D,E)

CED-TI&E-T-9



FTR450261000U
3 Jan 1983

# TI&E DICE—SHEET METAL LINEAL SHAPES

## ALUMINUM

### TI&E MAN-HOURS CHARACTERISTICS INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Straight Brake Formed | All | 0.007 | 0.006 | | 0.006 | | | |
| • Cylindrically Contoured | 24" & 48" | 0.008 | 0.006 | | | 0.010 | | 0.053 |
| • Brake and Roll Formed | 96" & 144" | 0.008 | 0.006 | | | 0.010 | | 0.063 |
| • Non-Cylindrically Contoured | 24" & 48" | 0.014 | 0.008 | | 0.010 | 0.010 | | 0.053 |
| • Rubber Press Formed | 96" & 144" | 0.014 | 0.008 | | 0.010 | 0.010 | | 0.063 |
| • Non-Cylindrically Contoured | 24" & 48" | 0.008 | 0.006 | | | 0.010 | | 0.053 |
| • Brake & Stretch Formed | 96" & 144" | 0.008 | 0.006 | | | 0.010 | | 0.063 |

A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

DICE-TI&E-1

# TI&E DICE—SHEET METAL NON-LINEAL SHAPES

## ALUMINUM

### TI&E MAN-HOURS PER CHARACTERISTIC INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Flat Sheet<br>• Rout | All | | | | | | | |
| • Cylindrical Curvature Skin<br>• Farnham Roll | All | | | | 0.010 | | | |
| • Non-Cylindrical Curvature Skin<br>• Stretch Form | All | | | | 0.010 | | | |
| • Fairing<br>• Drop Hammer | All | | | | 0.010 | | | |
| • Rib<br>• Rubber Press | All | 0.012 | 0.008 | | 0.010 | 0.010 | | |
| • Beaded Panel<br>• Rubber Press | All | | | | 0.010 | | | |

A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

DICE-TI&E-2

# TI&E DICE—SHEET METAL LINEAL SHAPES

## TITANIUM

### TI&E MAN-HOURS PER CHARACTERISTIC INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Straight<br>• Brake Formed<br>• Room Temperature | All | 0.007 | 0.006 | | 0.006 | 0.010 | | |
| • Straight<br>• Preform and Hot Size | All | 0.007 | 0.006 | | 0.006 | 0.010 | | |
| • Contoured<br>• Preform and Hot Size | All | 0.012 | 0.008 | | 0.010 | 0.010 | | |
| • Contoured<br>• Brake and Hot Stretch | All | 0.008 | 0.007 | | | 0.010 | | |

A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

DICE-TI&E-3

# TI&E DICE—SHEET METAL NON-LINEAL SHAPES

## TITANIUM

### TI&E MAN-HOURS PER CHARACTERISTIC INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Cylindrically Contoured Skin<br>• Farnham Roll | All | | | | 0.012 | 0.010 | | |
| • Non-Cylindrically Contoured Skin<br>• Creep Form | All | | | | 0.012 | 0.010 | | |
| • Frame<br>• Hot Press | All | 0.012 | 0.008 | | 0.010 | 0.010 | | |

A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

DICE-TI&E-4

# TI&E DICE—SHEET METAL LINEAL SHAPES

## STEEL

### TI&E MAN-HOURS PER CHARACTERISTIC INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Straight<br>• Brake Formed | All | 0.007 | 0.006 | | 0.006 | 0.008 | | |
| • Contoured<br>• Brake and Roll | All | 0.007 | 0.006 | | | 0.010 | | |
| • Contoured<br>• Rubber Press | All | 0.012 | 0.008 | | 0.010 | 0.010 | | |

A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

DICE-TI&E-5

# TI&E DICE—SHEET METAL NON-LINEAL SHAPES

## STEEL

### TI&E MAN-HOURS PER CHARACTERISTIC INSPECTED

| PART & METHOD | SIZE | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| • Cylindrically Contoured Skin<br>• Farnham Roll | All | | | | 0.016 | 0.010 | | |
| • Non-Cylindrically Contoured Skin<br>• Stretch Form | All | | | | 0.016 | 0.010 | | |
| • Frame<br>• Rubber Press | All | 0.012 | 0.008 | | 0.010 | 0.010 | | |

A. Standard Joggle
B. Standard Flanged Hole
C. Heat Treatment (Removed from DICE)
D. Cutout Without Flanges
E. Trim-Lineal, Ends, Corners
F. Clean
G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

DICE-TI&E-6

### 4.7.1.4 Ground Rules for Test, Inspection & Evaluation (TI&E) of Sheet Metal Section

The following General and Detailed Ground Rules for the Section on Test, Inspection & Evaluation (TI&E) of Sheet Metal were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

#### 4.7.1.4.1 General Ground Rules

The general ground rules are categorized under the following major groups:

(a) TI&E of Sheet Metal Discrete Parts

(b) Materials

(c) TI&E Methods

(d) Facilities & Equipment

(e) Data Generation - TI&E Recurring Costs

(f) Data Generation - TI&E Nonrecurring Costs

(g) Support Function Modifiers

(h) Test and Evaluation of Data.

(a) TI&E of Sheet Metal Discrete Parts

(1) The aerospace sheet metal discrete parts are those depicted in the MC/DG demonstration section and are representative of common structural parts required for both small and large aircraft.

(2) The TI&E section will include only those parts identified and described in the MC/DG sheet metal demonstration section.

(3) The selected discrete parts will be defined and dimensioned in such a manner that it will enable the TI&E effort to adequately display the effect on part cost of DICE, e.g., nondestructive test (NDT).

(b) Materials

(1) The materials are as specified in the MC/DG sheet metal section, i.e., aluminum, steel, and titanium.

(c) TI&E Methods

(1) Only conventional methods required to test, inspect, and evaluate the sheet metal parts in the configurations selected will be considered.

(2) A production, in contrast to a prototype, environment will be assumed for the TI&E of sheet metal aerospace discrete parts.

(3) To generate an effective TI&E data base for each selected part, a quality assurance operational sequence for each discrete part type will be established, reflecting the most economical inspection procedures. This standardized sequence will be used by each team member to determine the TI&E cost.

(d) Facilities and Equipment

(1) Only standard quality assurance facilities and equipment available to the airframe industry will be considered.

(e) Data Generation - Recurring Costs

(1) Recurring man-hour data will be generated for the TI&E in part fabrication and will, therefore, include all the TI&E functions from the release of part to production operations through final inspection.

(2) The base part TI&E man-hours will be generated for each part.

(3) The TI&E DICE elements will be treated as separate cost elements, and therefore, will not be included in the TI&E base cost.

(4) The quantity for which the base part and the DICE TI&E cost will be determined is at unit 200. A lot size of 25 will be applied.

(5) Cost data will be presented in standard man-hours.

(6) Recurring tooling TI&E costs (tool maintenance, tool calibration, etc.) will not be included.

(7) The TI&E data submitted to BCL will be the base part TI&E costs (standard man-hours) plus the TI&E cost (standard man-hours) of DICE associated with the discrete part design.

(8) In developing TI&E cost data for parts, each participating company may utilize its own proprietary improvement curves.

(9) The TI&E costs (standard man-hours), as derived by each contributing team member company, will be normalized by BCL to reflect an industry team average.

(10) For proprietary reasons, business sensitive information employed at team member contributing companies will not be presented in the MC/DG.

(11) No data provided by any team member will be disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(f) Data Generation - Nonrecurring Costs

(1) Tool inspection TI&E cost will be generated for each part type.

(2) TI&E planning (quality planning) costs will be evaluated with respect to their impact to determine whether they should be included or omitted.

(3) The TI&E cost of production tooling, if included, will be restricted to contract or project tools only for presentation in the MC/DG.

(4) Nonrecurring tooling costs (NRTC) generated by team companies will be normalized by BCL to reflect an industry team average.

(g) Support Function Modifiers

(1) Additional effort, other than direct factory labor and TI&E, will be excluded from the part cost data supplied to BCL. Other modifiers may be included later by the MC/DG user at airframe companies.

(h) Test and Evaluation of Data

(1) Test and confirmation of the formats and integrated data will be accomplished by one team member. Each of the remaining team members will be provided with the evaluation. Any anomalies will be resolved and modifications incorporated as appropriate.

4.7.1.4.2 Detailed Ground Rules

The detailed ground rules for TI&E will be categorized under the following major groups:

(a) Materials
(b) Tolerances
(c) Discrete parts
(d) Quality control methods
(e) Inspection operations.

(a) Materials

(1) The materials selected for sheet metal discrete parts will be:

- Aluminum (2024)
- Titanium (6Al-4V)
- Steel (PH 15-7Mo).

(2) Treatment required for any of these materials to increase physical properties, or to improve formability, is to be indicated on the part sketches to enable adequate costing of the TI&E effort.

(b) Tolerances

(1) Parts will be assumed to be formed using standard bend radii as dictated by the material type and thickness.

(2) Parts will be assumed to be manufactured to a linear tolerance of ±0.030 inch and an angular tolerance of ±0° 30'.

(c) Discrete Parts

(1) Drawings of the sheet metal aerospace discrete parts showing configurations, dimensions, joggles, holes, trim, heat treatment, etc., will be used so that each team member may estimate TI&E base standard hours in a consistent manner.

(d) Quality Control

(1) Quality control methods used for the TI&E of the respective parts will be specified by an operational sequence for TI&E, and on a developed data collection form.

(2) Where more than one TI&E method exists to inspect a discrete part, data will be generated for each method to reveal the comparative cost relationships to the designer.

(e) Inspection Operations

(1) The following will be typical TI&E operations that should be evaluated:

- In-process material verification
- Dimensional
- NDT (penetrant)
- Hardness
- Finish system
- Identification.

## 4.7.2 TI&E for Mechanically Fastened Assemblies

### 4.7.2.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine TI&E cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide cost and cost-estimating data (CED) in man-hours for conducting trade-studies.

FORMAT SELECTION AID

# TEST, INSPECTION AND EVALUATION (TI&E) MECHANICALLY FASTENED ASSEMBLIES

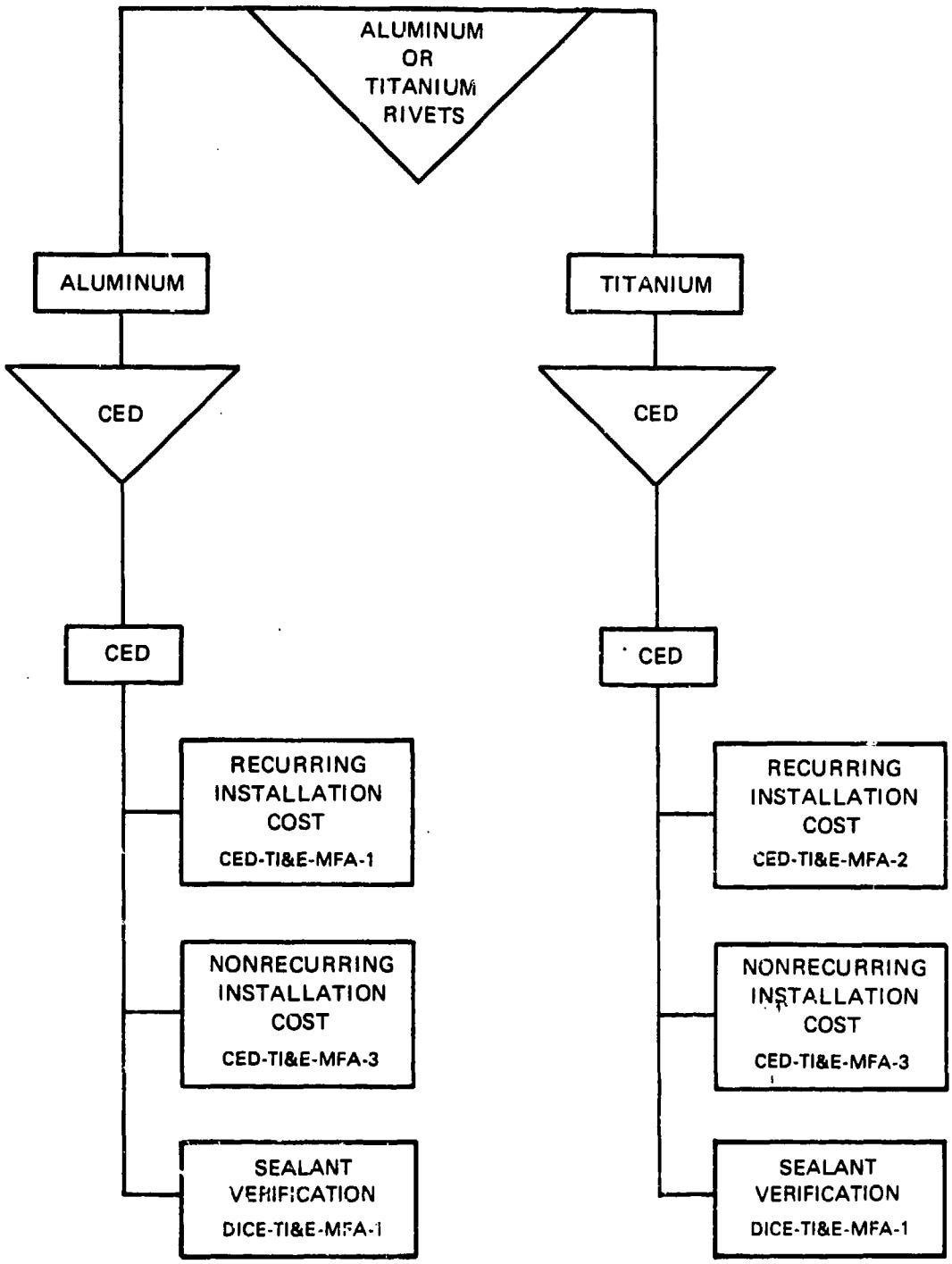



FIGURE 4.7.2-1

### 4.7.2.2 Example of Utilization

This example demonstrates to the designer how the mechanically fastened assembly data is utilized on a specific design problem. The example shows how to identify applicable formats, how to extract data from the formats, and provides a discussion on how the data are used to determine the TI&E cost in man-hours or dollars. The MC/DG cost worksheet can be used to record the cost data for easy reference and to determine the total program cost. The MC/DG worksheet appears as Table 3-3.

#### 4.7.2.2.1 Utilization Example for Mechanically Fastened Assembly

Problem Statement

Determine test, inspection, and evaluation (TI&E) cost (man-hours) for an aluminum (2024) first-level assembly as shown in Figure 4.7.2-2. The design quantity will be 200.

Procedure

The following procedure is used to determine the TI&E cost of the assembly:

1. Utilize the Format Selection Aid for Mechanically Fastened Assemblies TI&E (Figure 4.7.2-1).
2. Determine the formats to use. In this case, Formats CED-TI&E-MFA-1 (Fig. 4.7.2-3) and CED-TI&E-MFA-3 (Fig. 4.7.2-4) are required.
3. Study the formats to determine the parameters and conditions necessary for use. To use CED-TI&E-MFA-1, the number of fasteners and fastening method must be specified. The sketch indicates 133 fasteners with the faying surface sealed. For this example, manual and 80 percent automatic/20 percent manual riveting will be considered. To use CED-TI&E-MFA-3, the number of fasteners is required.
4. Determine the values for recurring cost and nonrecurring tooling cost (NRTC) from the formats:

   (a) Manual

   - Recurring cost at unit 200 = 0.71 man-hours per part
   - NRTC = 1.75 man-hours per 200 parts
     = 0.009 ≈ 0.01 man-hours per part
   - The learning curve factor to convert unit cost at 200 to cumulative average cost for an 80 percent curve and a quantity of 200 is 1.45 (see Table 4.7.2-1).

   Total cost = 1.45 (0.71) + 0.01 = 1.04 man-hours per part.

(b) 80 percent Automatic/20 percent Manual

- Recurring cost at unit 200 = 0.64 man-hours per part
- NRTC = 1.75 man-hours per 200 parts
  = 0.009 ≈ 0.01 man-hours per part.

Total cost = 1.45 (0.64) + 0.01 = 0.94 man-hours per part.

5. Check for applicable DICE. The drawing specifies that the faying survace be sealed. This condition is found on DICE-TI&E-MFA-1 (Fig. 4.7.2-5). The parameters for utilization of this format are the part area and the sealing requirements. The part area is 56.30/12 x 30.15/12 = 11.79 $ft^2$. The sealing requirements state that the faying surface must be sealed. Given these parameters, the TI&E DICE cost is 0.13 man-hours for this part.

6. Calculate the total cost. From the data above, the total costs are:

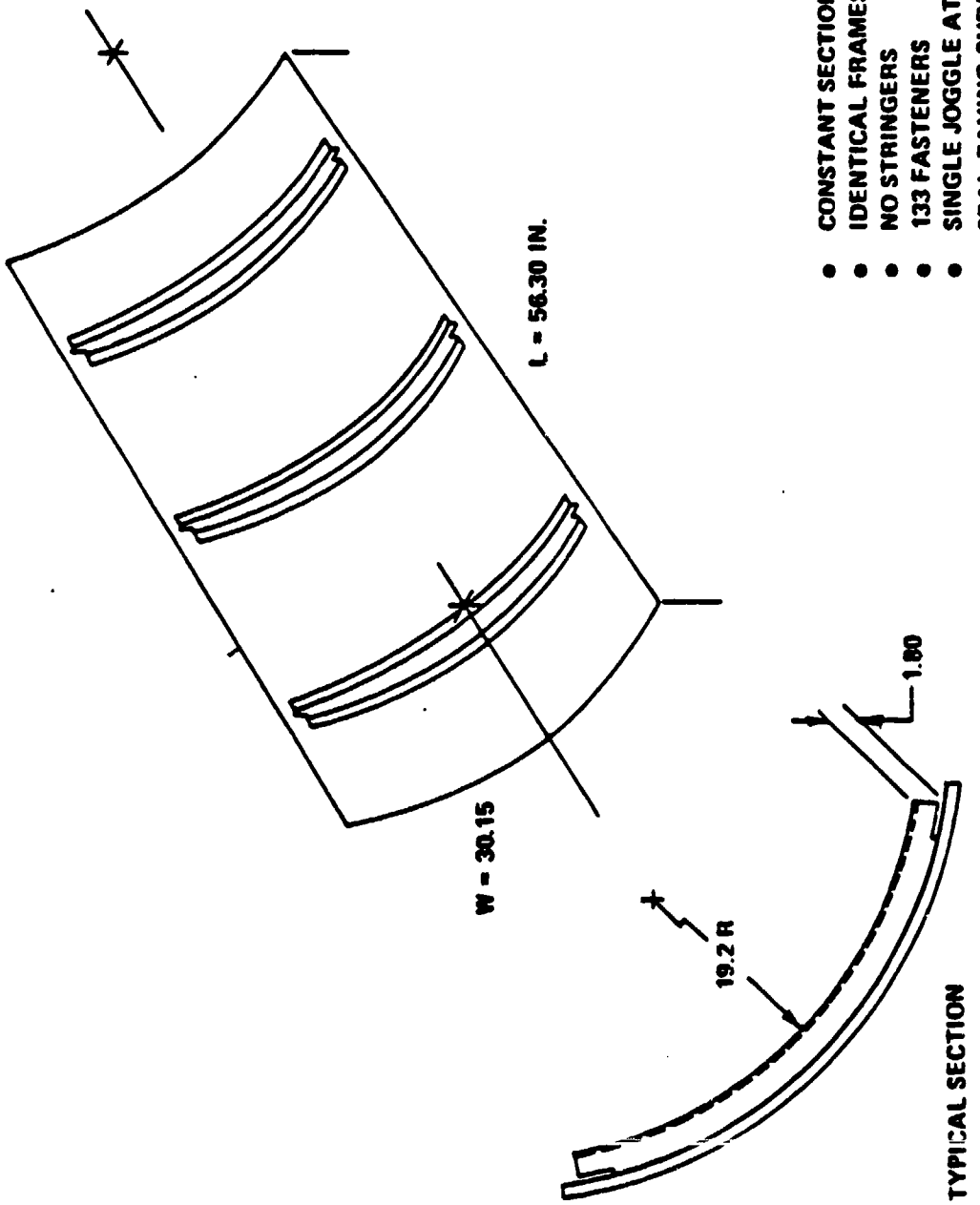
   (a) Manual

   1.45 (0.71 + 0.13) + 0.01 = 1.23 man-hours per part

   (b) 80 percent automatic/20 percent manual

   1.45 (0.64 + 0.13) + 0.01 = 1.23 man-hours per part.

   Thus, inspection is less costly for the combined automatic/manual fastening method.




- CONSTANT SECTION RADIUS
- IDENTICAL FRAMES
- NO STRINGERS
- 133 FASTENERS
- SINGLE JOGGLE AT FRAME ENDS
- SEAL FAYING SURFACES

FIGURE 4.7.2-2. ALUMINUM (2024) FIRST-LEVEL ASSEMBLY STUDIED

# TEST, INSPECTION AND EVALUATION (TI&E) RECURRING MAN-HOURS FOR MECHANICALLY FASTENED ALUMINUM ASSEMBLIES

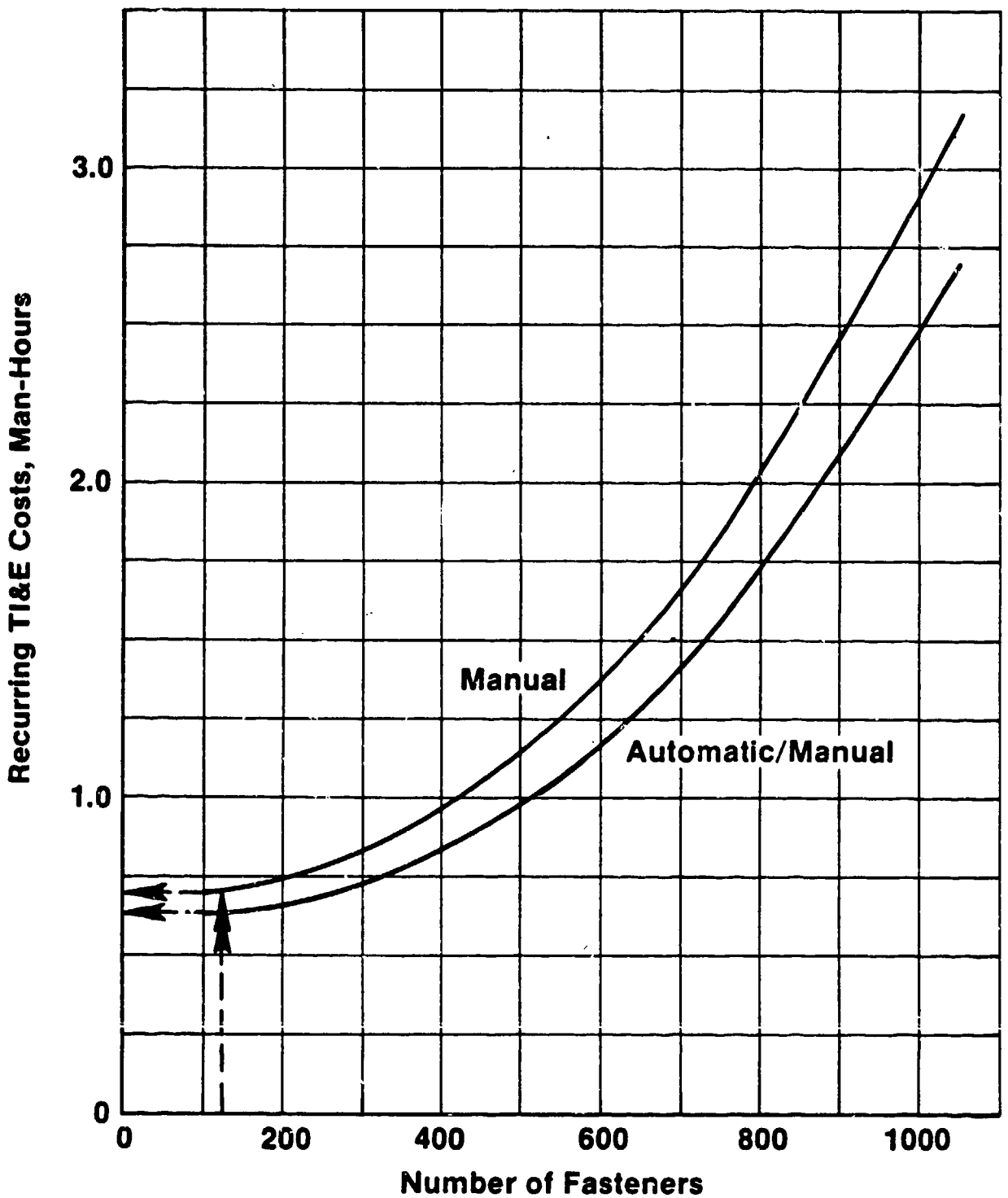



FIGURE 4.7.2-3. FORMAT USED IN EXAMPLE

CED-TI&E-MFA-1

# TEST, INSPECTION AND EVALUATION (TI&E) NONRECURRING TI&E MAN-HOURS FOR ALUMINUM AND TITANIUM ASSEMBLIES USING MANUAL OR COMBINED AUTOMATIC/ MANUAL FASTENING METHODS

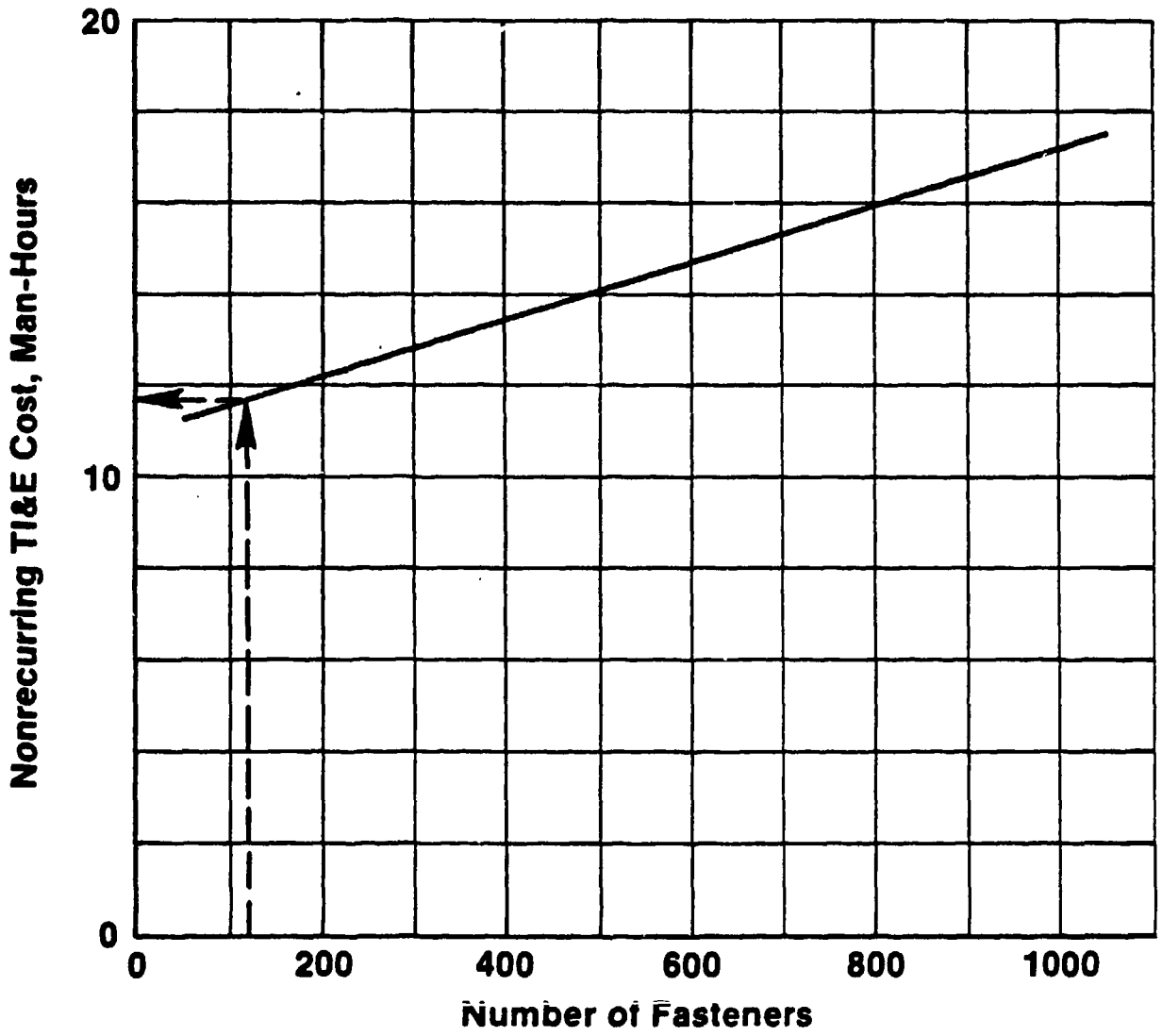



FIGURE 4.7.2-4. FORMAT USED IN EXAMPLE

CED-TI&E-MFA-3

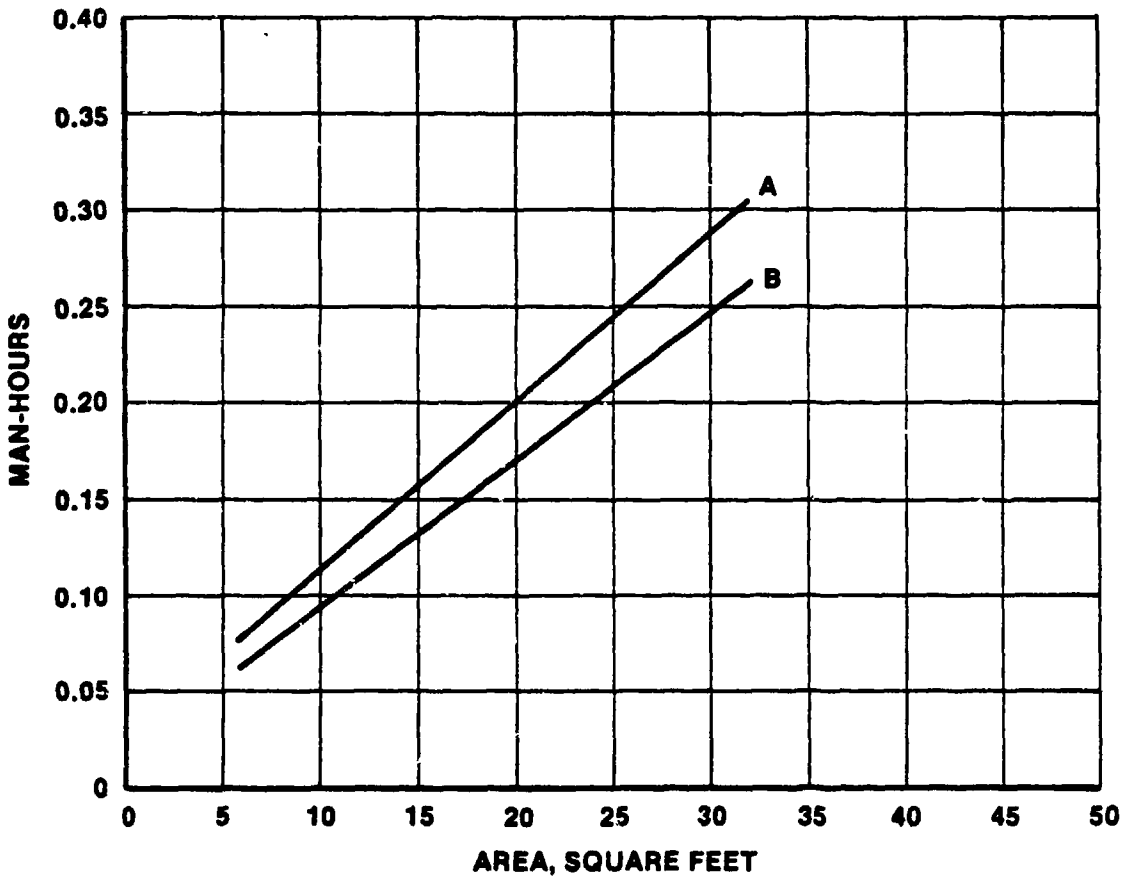
TABLE 4.7.2-1

## FACTORS TO CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED

| DESIGN QUANTITY | LEARNING CURVE-% | | | | | | |
|---|---|---|---|---|---|---|---|
| | 95 | 90 | 85 | 80 | 75 | 70 | 65 |
| 1 | 1.48 | 2.25 | 3.48 | 5.50 | 9.00 | 15.00 | 27.00 |
| 10 | 1.33 | 1.79 | 2.47 | 3.48 | 5.04 | 7.53 | 11.67 |
| 25 | 1.25 | 1.59 | 2.05 | 2.71 | 3.68 | 5.13 | 7.43 |
| 50 | 1.19 | 1.44 | 1.79 | 2.22 | 2.85 | 3.76 | 5.14 |
| 100 | 1.13 | 1.30 | 1.52 | 1.80 | 2.18 | 2.73 | 3.51 |
| 200 | 1.08 | 1.17 | 1.30 | 1.45 | 1.66 | 1.95 | 2.36 |
| 350 | 1.04 | 1.08 | 1.14 | 1.22 | 1.33 | 1.48 | 1.70 |
| 500 | 1.01 | 1.02 | 1.05 | 1.09 | 1.15 | 1.24 | 1.38 |
| 750 | 0.98 | 0.96 | 0.96 | 0.96 | 0.97 | 1.01 | 1.09 |
| 1000 | 0.96 | 0.92 | 0.89 | 0.87 | 0.87 | 0.88 | 0.91 |

# TEST, INSPECTION AND EVALUATION (TI&E) MECHANICALLY FASTENED ASSEMBLIES

## RECURRING COST/PART FOR TI&E OF DICE FOR ALUMINUM AND TITANIUM ASSEMBLIES USING MANUAL OR COMBINED AUTOMATIC/MANUAL FASTENING METHODS




(A) PERMISSIBLE TO SEAL AND VERIFY SEALANT ON FASTENER AND FAYING SURFACE
(B) PERMISSIBLE TO SEAL AND VERIFY SEALANT ON FASTENER ONLY

FIGURE 4.7.2-5. FORMAT USED IN EXAMPLE



DICE-TI&E-MFA-1

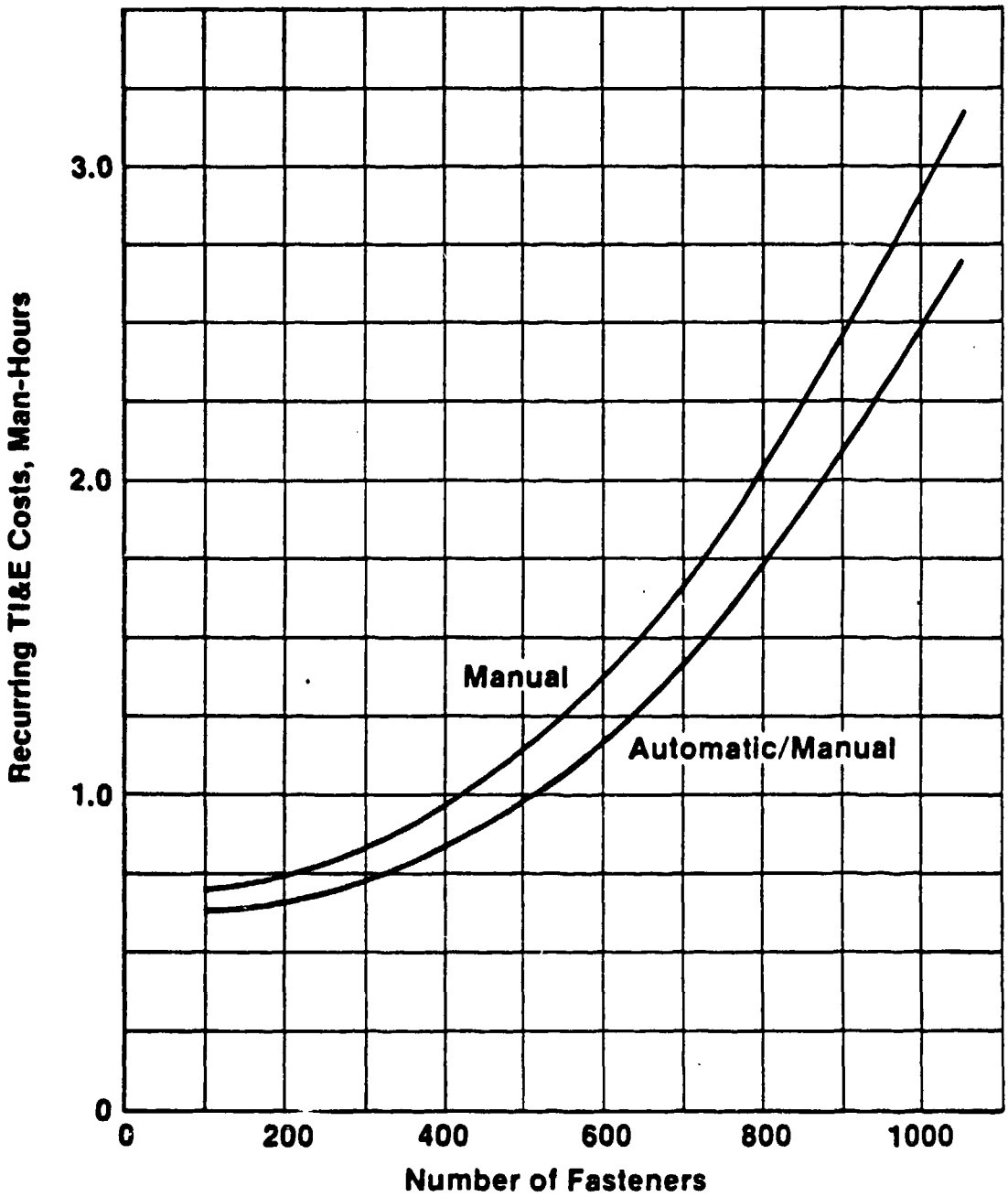
#### 4.7.2.3 Airframe Assemblies Analyzed

The airframe assemblies analyzed to determine the TI&E man-hours are those studied in Section 4.2 "Mechanically Fastened Assemblies" (Figures 4.2-4 to 4.2-7).

#### 4.7.2.4 TI&E Data for Airframe Assemblies

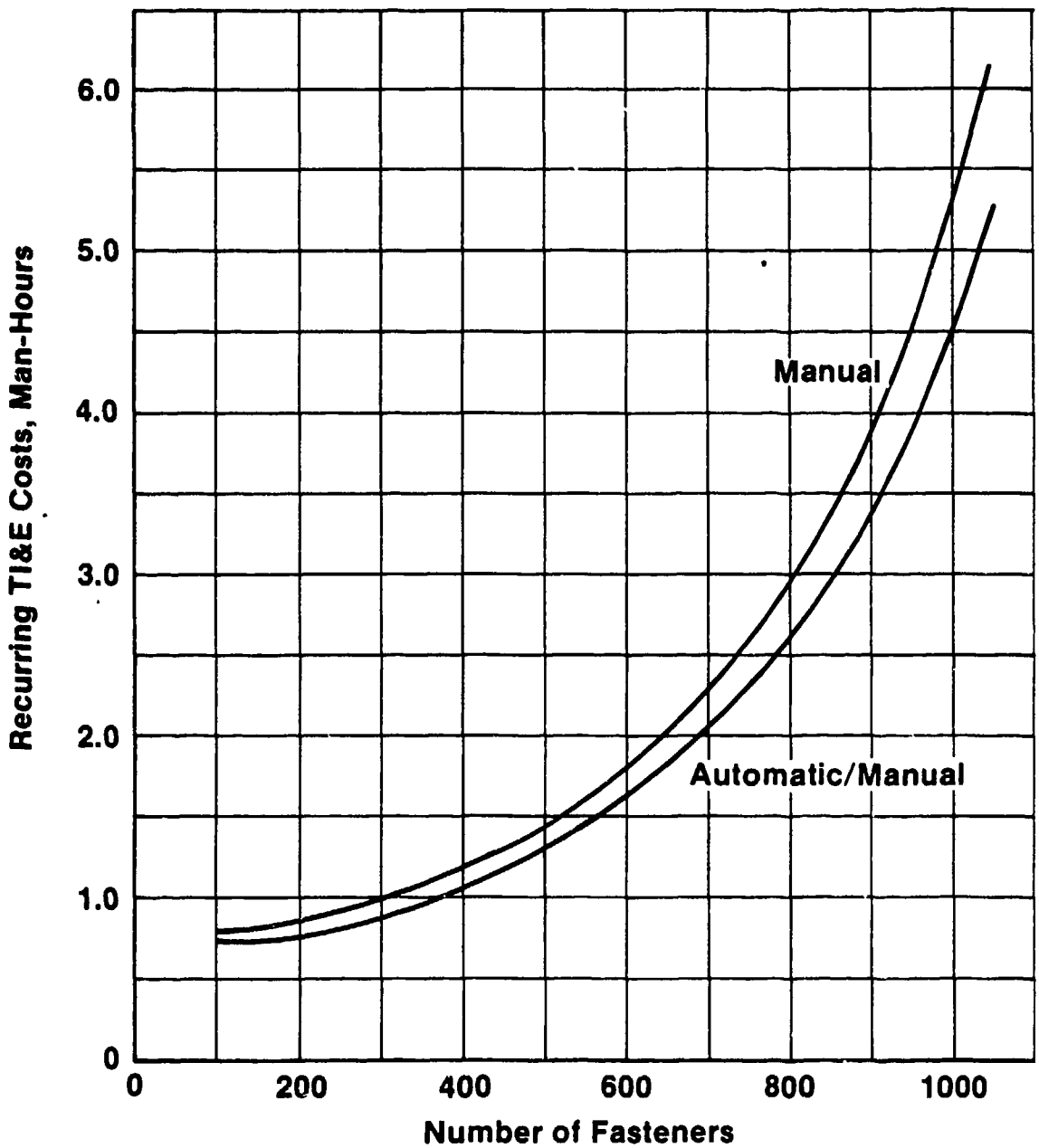
The TI&E data for airframe assemblies on the following pages are presented to the designer using cost-estimating data (CED) and designer-influenced cost element (DICE) formats for trade-studies.

# TEST, INSPECTION AND EVALUATION (TI&E) RECURRING MAN-HOURS FOR MECHANICALLY FASTENED ALUMINUM ASSEMBLIES



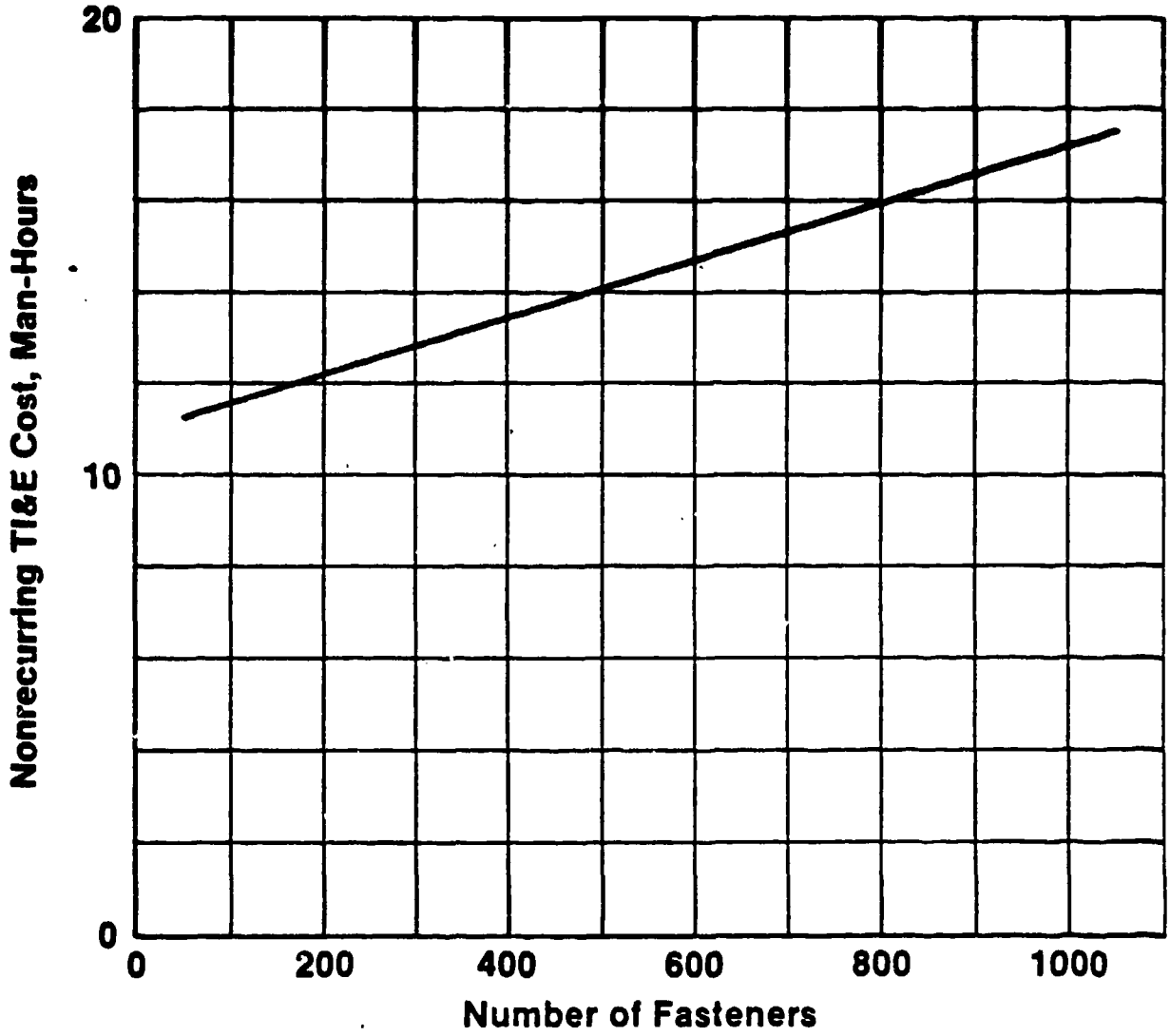

CED-TI&E-MFA-1

# TEST, INSPECTION AND EVALUATION (TI&E) RECURRING MAN-HOURS FOR MECHANICALLY FASTENED TITANIUM ASSEMBLIES




CED-TI&E-MFA-2

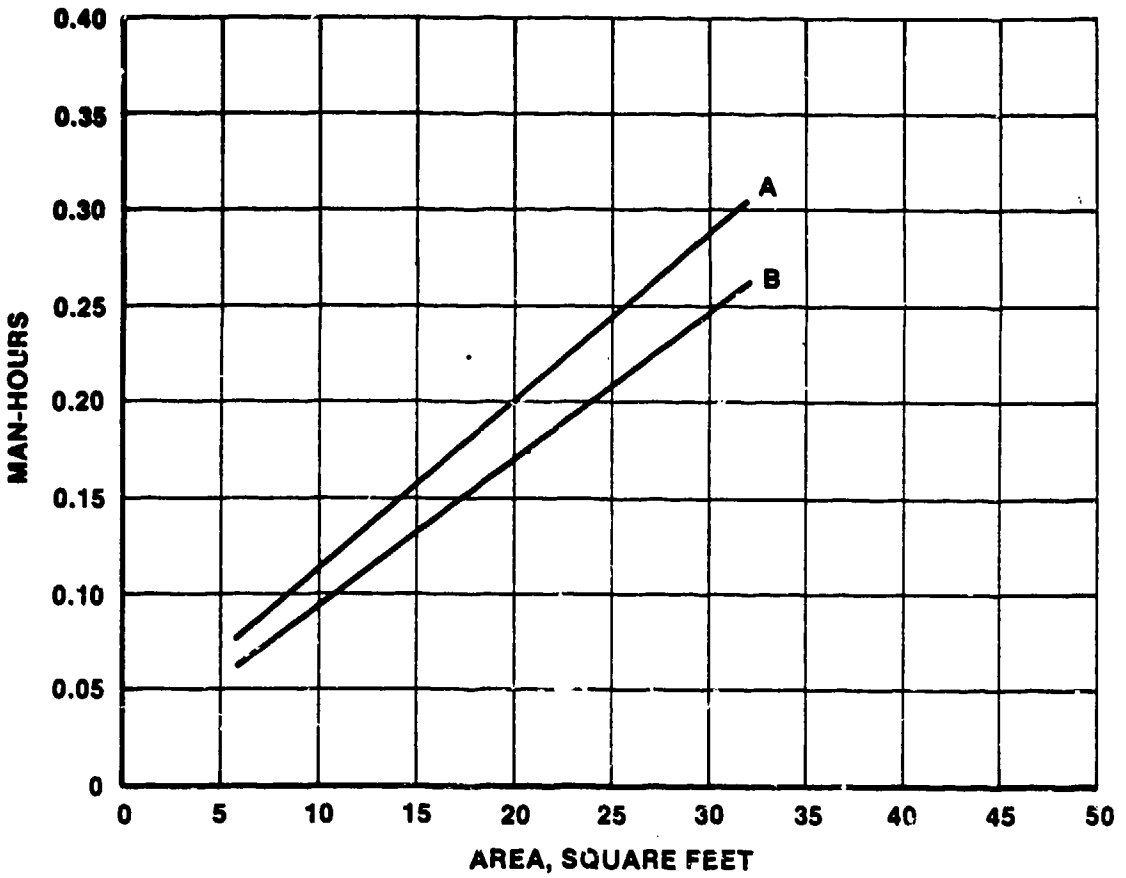
# TEST, INSPECTION AND EVALUATION (TI&E) NONRECURRING TI&E MAN-HOURS FOR ALUMINUM AND TITANIUM ASSEMBLIES USING MANUAL OR COMBINED AUTOMATIC/ MANUAL FASTENING METHODS




CED-TI&E-MFA-3

# TEST, INSPECTION AND EVALUATION (TI&E) MECHANICALLY FASTENED ASSEMBLIES

## RECURRING COST/PART FOR TI&E OF DICE FOR ALUMINUM AND TITANIUM ASSEMBLIES USING MANUAL OR COMBINED AUTOMATIC/MANUAL FASTENING METHODS




(A) PERMISSIBLE TO SEAL AND VERIFY SEALANT ON FASTENER AND FAYING SURFACE
(B) PERMISSIBLE TO SEAL AND VERIFY SEALANT ON FASTENER ONLY



DICE-TI&E-MFA-1

### 4.7.2.5 Ground Rules for Test, Inspection & Evaluation (TI&E) of Mechanically Fastened Assemblies Section

The following General and Detailed Ground Rules for the Section on Test, Inspection & Evaluation (TI&E) of Mechanically Fastened Assemblies were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

#### 4.7.2.5.1 General Ground Rules

The general ground rules are categorized under the following major groups:

(a) First Level Mechanically Fastened Assemblies (MFA)
(b) Materials
(c) TI&E Methods
(d) Facilities and Equipment
(e) Data Generation - TI&E Recurring Costs
(f) Data Generation - TI&E Nonrecurring Costs
(g) Support Function Modifiers
(h) Test and Evaluation of Data.

(a) First Level Mechanically Fastened Assemblies

(1) The selected mechanically fastened assemblies are those depicted in the MC/DG demonstration section and are representative of common first level assemblies required for both small and large aircraft.

(2) The majority of discrete parts used in these assemblies was selected from the demonstration section for "Sheet Metal Aerospace Discrete Parts."

(3) The selected assemblies are an avionics bay panel, a fuselage panel with a cutout and a fuselage door assembly. The cost driver of accessibility has therefore been limited to the configurations of these panels.

(b) Materials

(1) The materials selected for the TI&E procedures are:

- Aluminum - 2024
- Titanium - 6Al-4V.

(c) TI&E Methods

(1) Only conventional methods required to test, inspect, and evaluate the assemblies selected will be considered.

(2) A production, in contrast to a prototype, environment will be assumed for the TI&E of mechanically fastened assemblies.

(3) To generate an effective TI&E data base for the selected assemblies, a quality assurance operational sequence for each assembly will be established reflecting the most economical inspection procedure. This standardized sequence will be used by each team member to determine the TI&E man-hours cost.

(d) Facilities and Equipment

(1) Only standard quality assurance facilities and equipment available to the airframe industry will be considered.

(e) Data Generation - Recurring Costs

(1) Recurring man-hour cost data will be generated for the complete TI&E process for each of the selected assemblies.

(2) A TI&E cost will be generated for each assembly type, two sizes (24" x 36" and 48" x 96") aluminum and titanium, manual and semiautomatic or automatic/manual methods.

(3) TI&E DICE elements will be treated as separate cost elements and, therefore, not included in the TI&E base cost.

(4) The quantity for which the base part and DICE TI&E cost will be determined is at unit 200.

(5) TI&E man-hours associated with DICE and other cost drivers will be identified.

(6) Cost data will be presented in standard man-hours.

(7) TI&E time consists of the standard man-hours to set up and complete the TI&E procedures.

(8) Recurring tooling TI&E costs (tool maintenance, tool calibration, etc.) will not be included.

(9) The TI&E data submitted to BCL will be the base-part cost (standard man-hours) plus the TI&E costs (standard man-hours) of DICE associated with the discrete part design.

(10) In developing TI&E cost data for parts, each participating company may utilize its own proprietary improvement curves.

(11) The TI&E part cost (standard man-hours) as derived by each contributing team member company will be normalized by BCL to reflect an industry team average.

(12) For proprietary reasons, business sensitive information employed at team member contributing companies will not be presented in the MC/DG.

(13) No data provided by any team member will be disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(f) Data Generation - Nonrecurring Costs

(1) The TI&E tooling costs are to be developed for each assembly type, e.g., inspection of check fixtures, templates, etc.

(2) The TI&E of production tooling, if included, will be restricted to contract or project tools only for presentation in the MC/DG.

(3) Nonrecurring tooling costs (NRTC) generated by the team companies will be normalized by BCL to reflect an industry team average.

(g) Support Function Modifiers

(1) Additional effort other than quality control and assurance, such as manufacturing engineering and planning, will be excluded from the TI&E cost data supplied to BCL. Other modifiers may be included later by the MC/DG users at airframe companies.

(h) Test and Evaluation of Data

(1) Test and confirmation of the formats and integrated data will be accomplished by one team member. Each of the remaining team members will be provided with the evaluation. Any anomalies will be resolved and modifications incorporated as appropriate.

4.7.2.5.2 Detailed Ground Rules

(1) Assembly procedures to be evaluated for TI&E are:

(a) Manual installation
(b) Combination manual and automatic installation
(c) DICE - Wet and dry installation of fasteners and faying surface seal.

(2) Fastener installation types to be evaluated are:

(a) Upset rivets
- Aluminum panels - AD rivets
- Titanium panels - Bimetallic titanium rivets

(b) HI-LOK pin/collar.

(3) Tolerances - location and hole sizes corresponding to individual team company standards will be evaluated.

(4) Rivet head flushness will be evaluated to individual company standards.

(5) All assemblies will be evaluated in aluminum and titanium materials.

(6) All detail parts and fasteners used in the assemblies are assumed to have been inspected and accepted in prior operations.

(7) No master hard points or interchangeability requirements.

(8) The following assemblies will be evaluated for both manual and combination automatic/manual:

| | |
|---|---|
| IIa -AL -1- A* | IIa -TI -1- A* |
| IIa -AL -1- D* | IIa -TI -1- D* |
| IIa -AL -2- A | IIa -TI -2- A |
| IIa -AL -2- D | IIa -TI -2- D |
| IIa -AL -3- A | IIa -TI -3- A |
| IIa -AL -3- D | IIa -TI -3- D. |

*DICE will be evaluated and reported.

## 4.7.3 TI&E for Castings

### 4.7.3.1 Format Selection Aid

The format selection aid is presented in Fig. 4.7.3-1 to provide the user with a building-block approach for determining TI&E cost data for alternative designs and casting processes. The designer can review the format selection aid and identify those areas that have an impact on his design. The formats provide cost-estimating data (CED), in man-hours, for conducting trade-off studies.

### 4.7.3.2 Example of Utilization

#### 4.7.3.2.1 Utilization Example for Bell Crank

**Problem Statement**

The utilization example for TI&E for Castings has been integrated with the utilization example determining the manufacturing cost of a cast bell crank. This example is described in Section 4.5.2.1 of Volume 2 (UM 450261000).

# MANUFACTURING COST/DESIGN GUIDE (MC/DG)

## FORMAT SELECTION AID
## TEST, INSPECTION AND EVALUATION (TI&E)
## CASTINGS

### COST ESTIMATING DATA

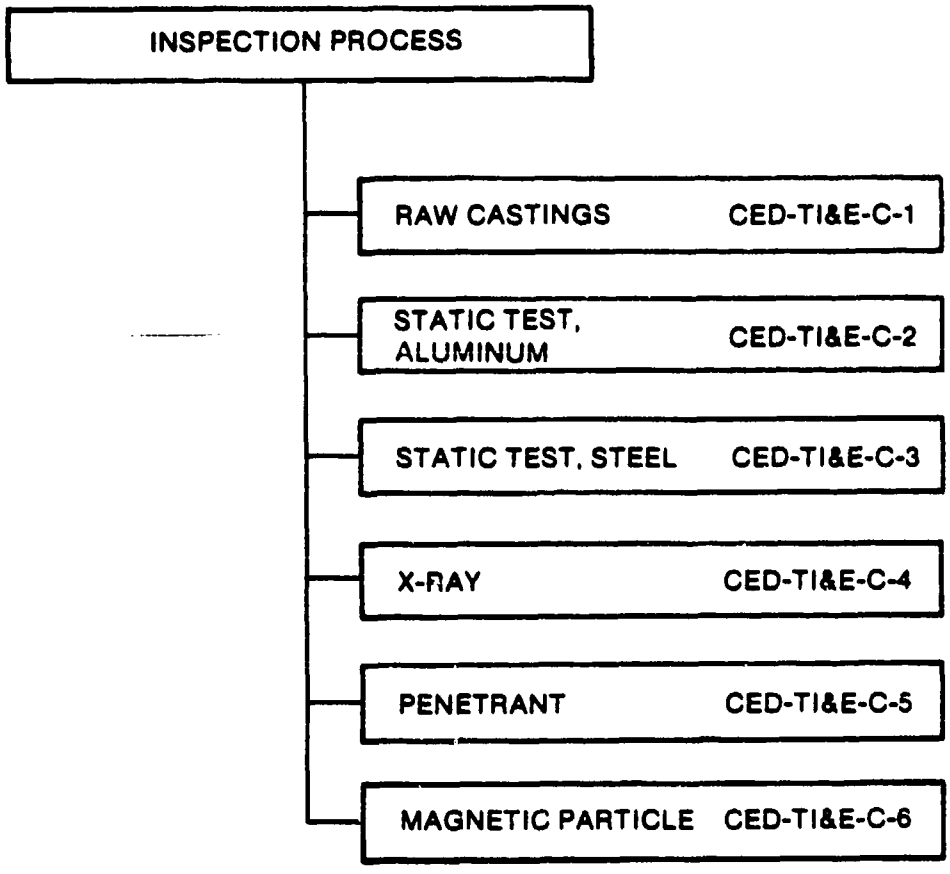


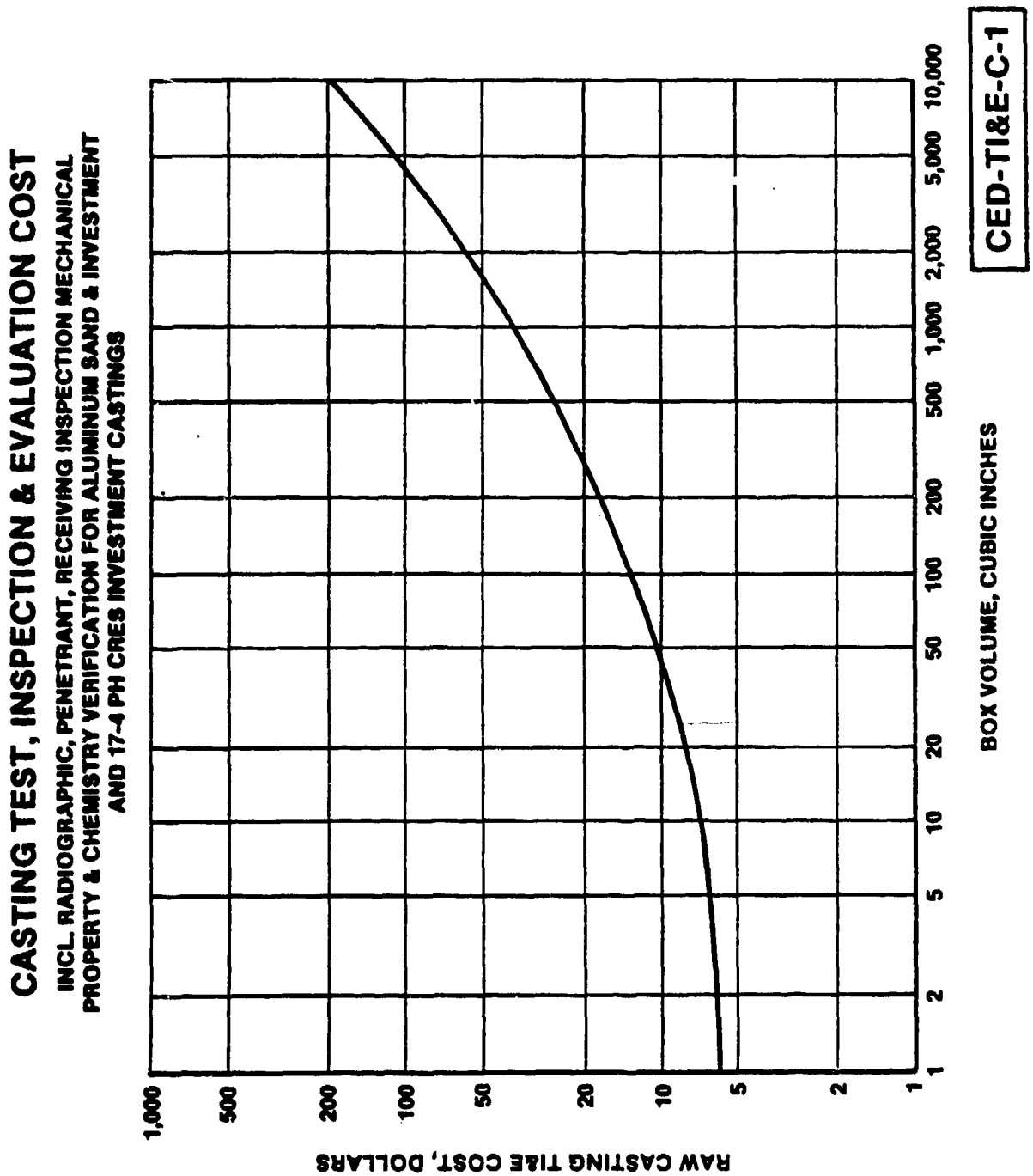

FIGURE 4.7.3-1

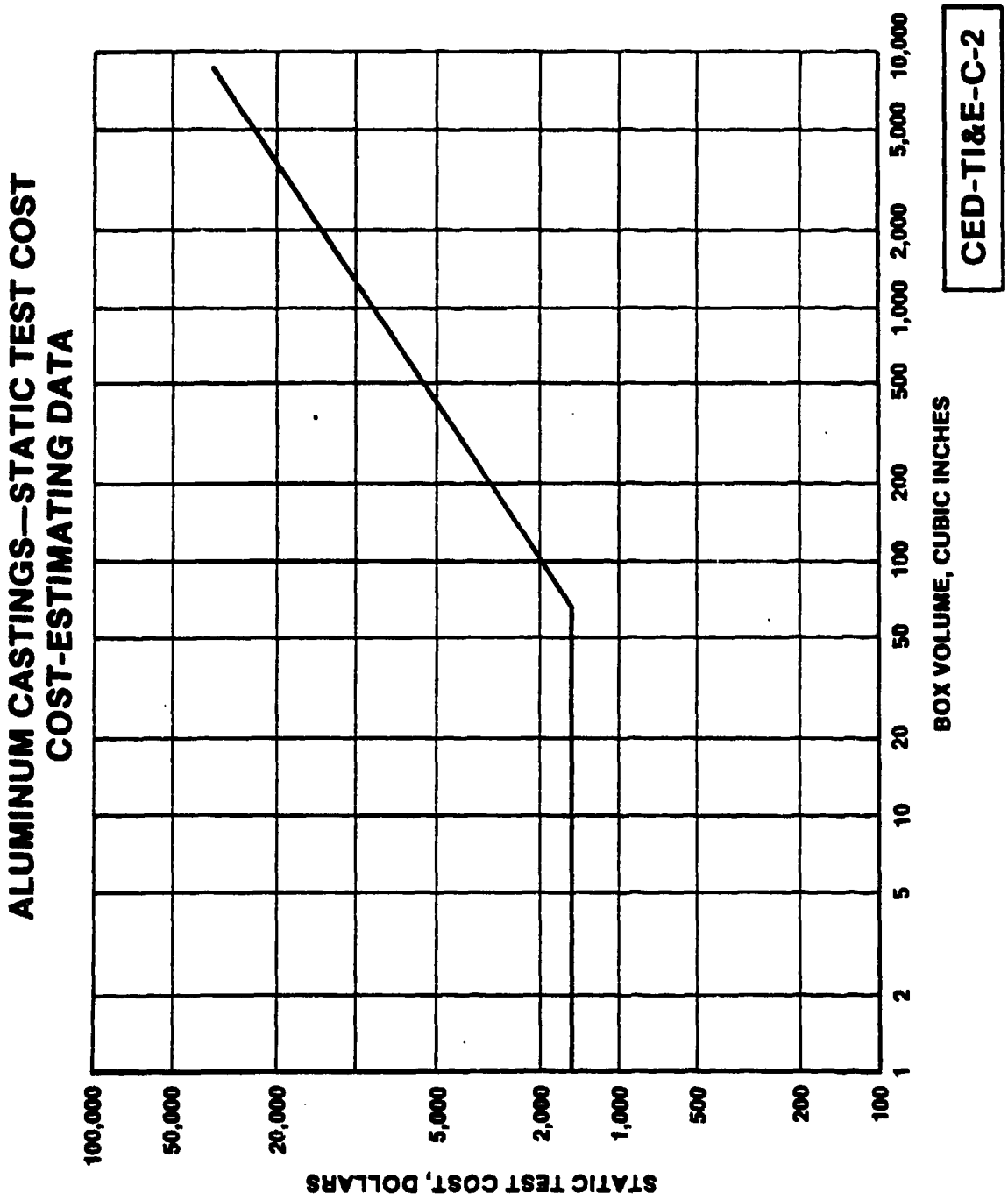
4.7.3.2 Casting Parts Analyzed

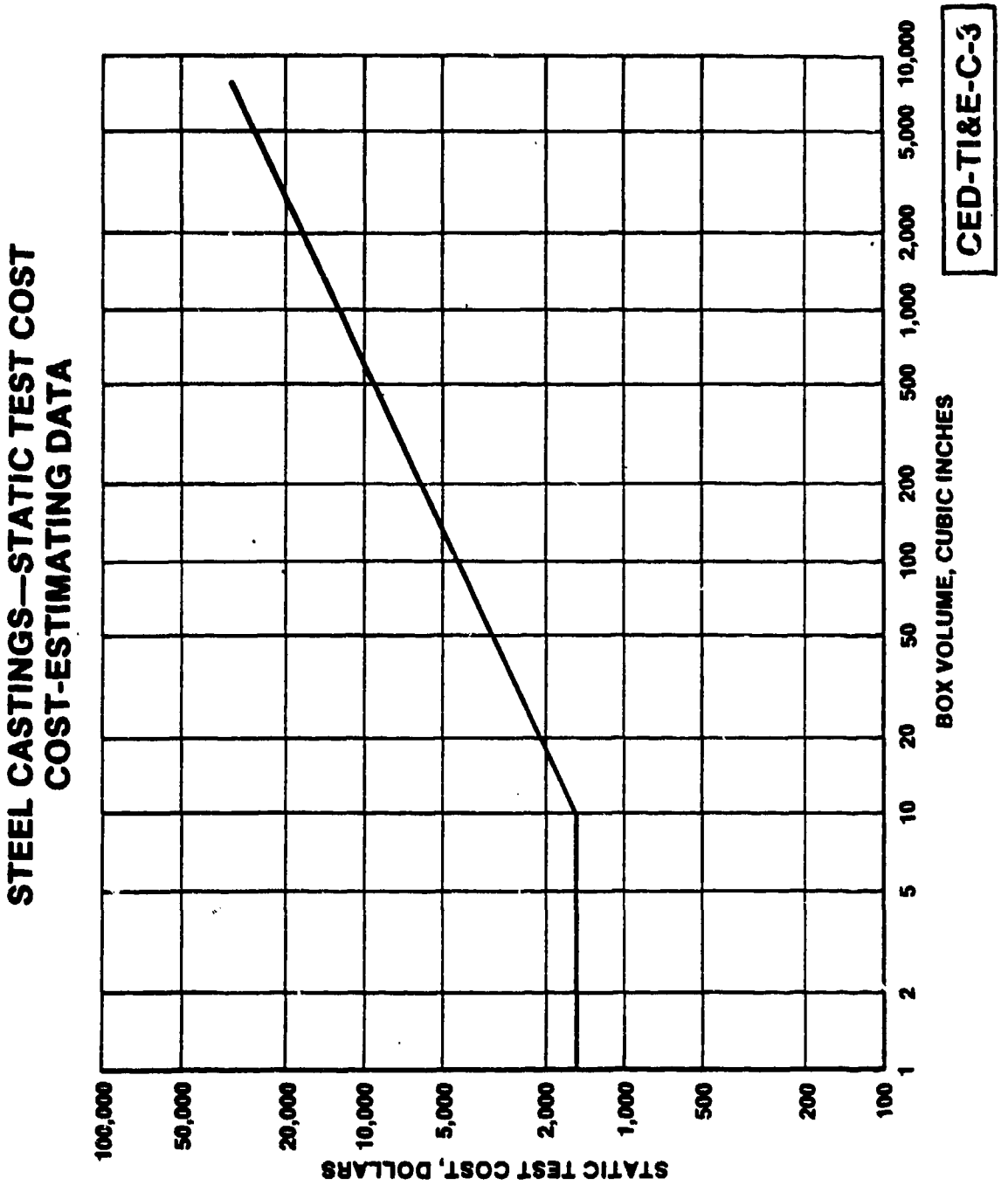
The casting parts analyzed are identical to those shown in MC/DG Section 4.5.

4.7.3.3 TI&E Data for Castings

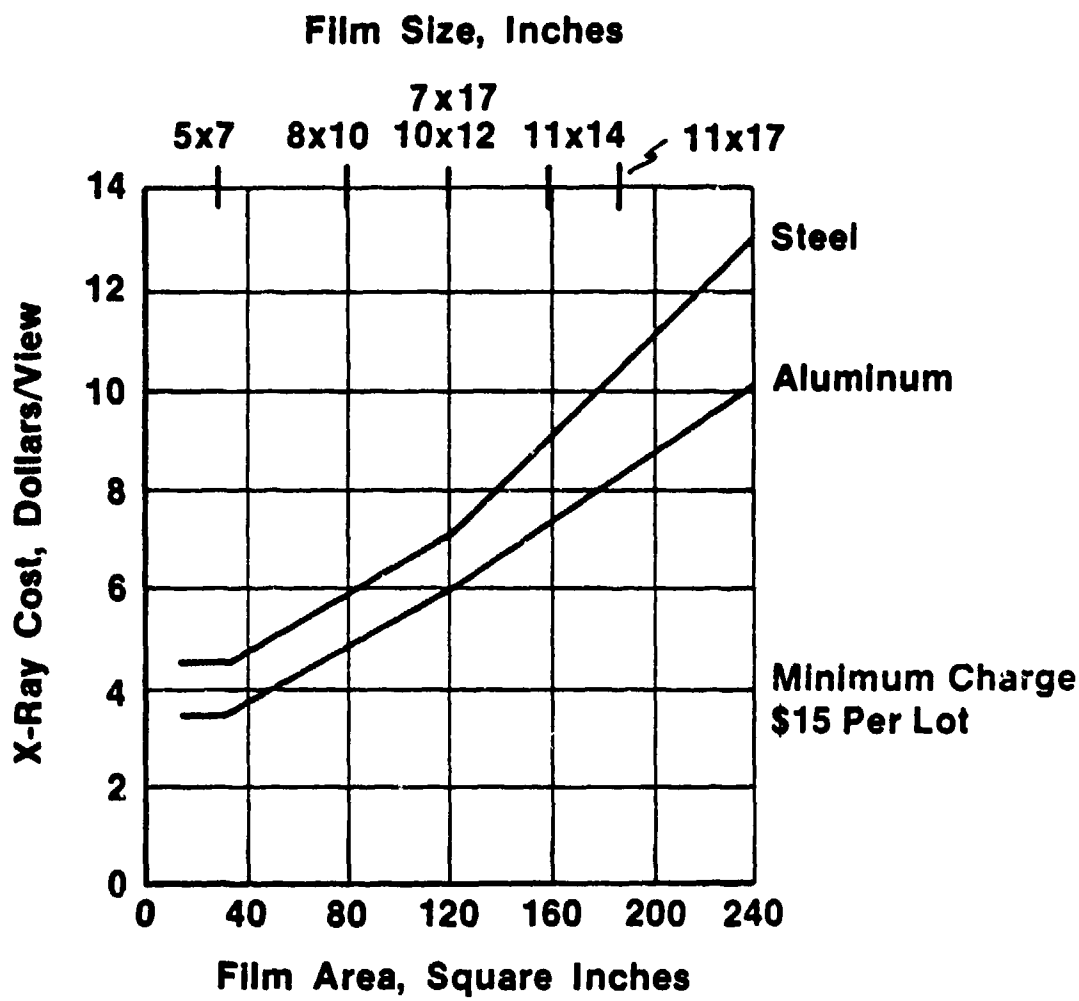
The data developed for designer guidance and to conduct trade-studies are presented on CED and DICE formats on the following pages. The data supplements that provided for the manufacturing processes for castings in Section 4.5.


CASTING TEST, INSPECTION & EVALUATION COST
INCL. RADIOGRAPHIC, PENETRANT, RECEIVING INSPECTION MECHANICAL PROPERTY & CHEMISTRY VERIFICATION FOR ALUMINUM SAND & INVESTMENT AND 17-4 PH CRES INVESTMENT CASTINGS
RAW CASTING TIME COST, DOLLARS
1,000
500
200
100
50
20
10
5
2
1
1
2
5
10
20
50
100
200
500
1,000
2,000
5,000
10,000
BOX VOLUME, CUBIC INCHES
CED-TI&E-C-1

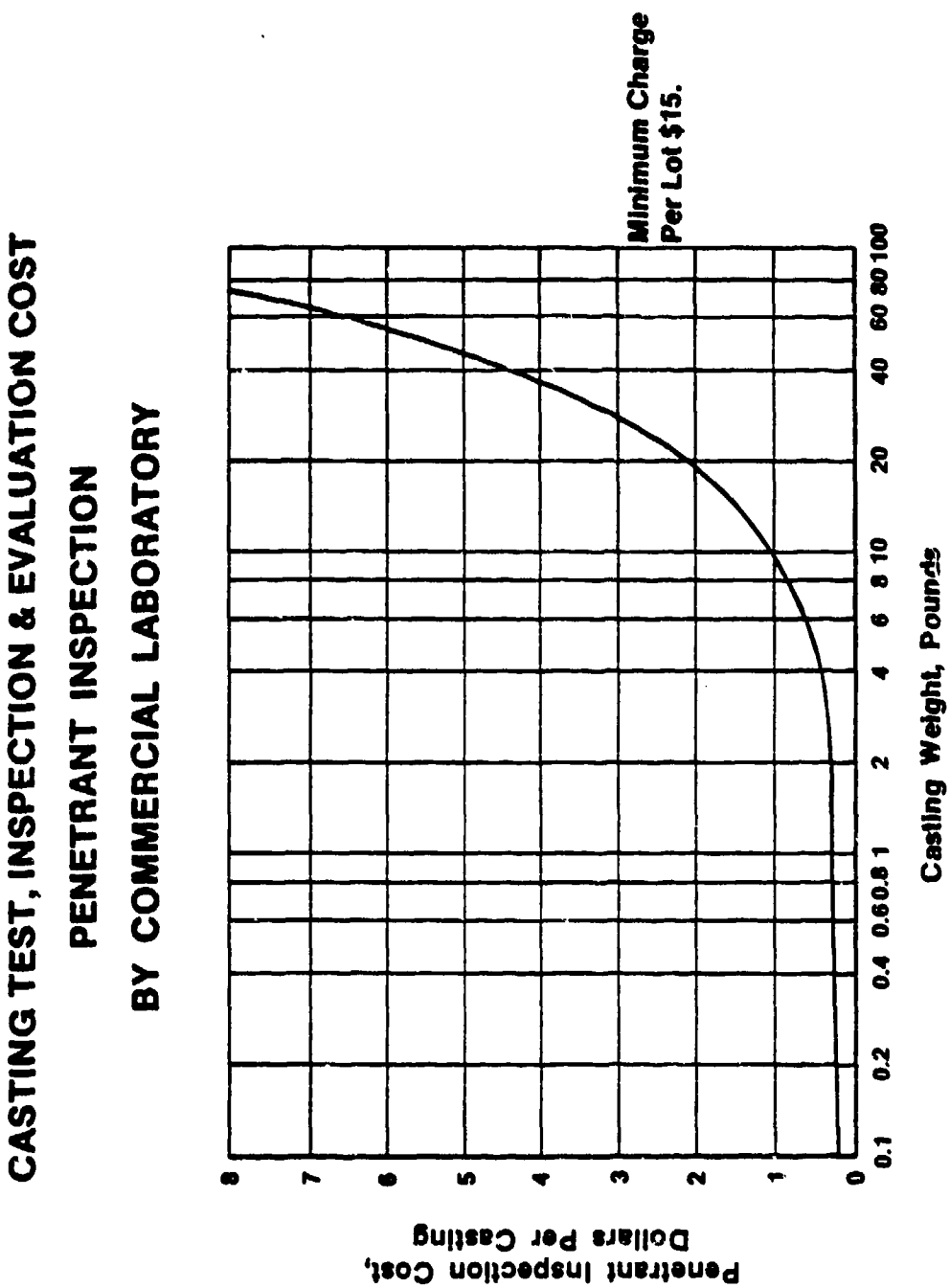

ALUMINUM CASTINGS—STATIC TEST COST
COST-ESTIMATING DATA
STATIC TEST COST, DOLLARS
100,000
50,000
20,000
5,000
2,000
1,000
500
200
100
BOX VOLUME, CUBIC INCHES
1
2
5
10
20
50
100
200
500
1,000
2,000
5,000
10,000
CED-TI&E-C-2


STEEL CASTINGS—STATIC TEST COST
COST-ESTIMATING DATA
STATIC TEST COST, DOLLARS
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100
BOX VOLUME, CUBIC INCHES
1
2
5
10
20
50
100
200
500
1,000
2,000
5,000
10,000
CED-TI&E-C-3

# CASTING TEST, INSPECTION & EVALUATION
## X-RAY COST

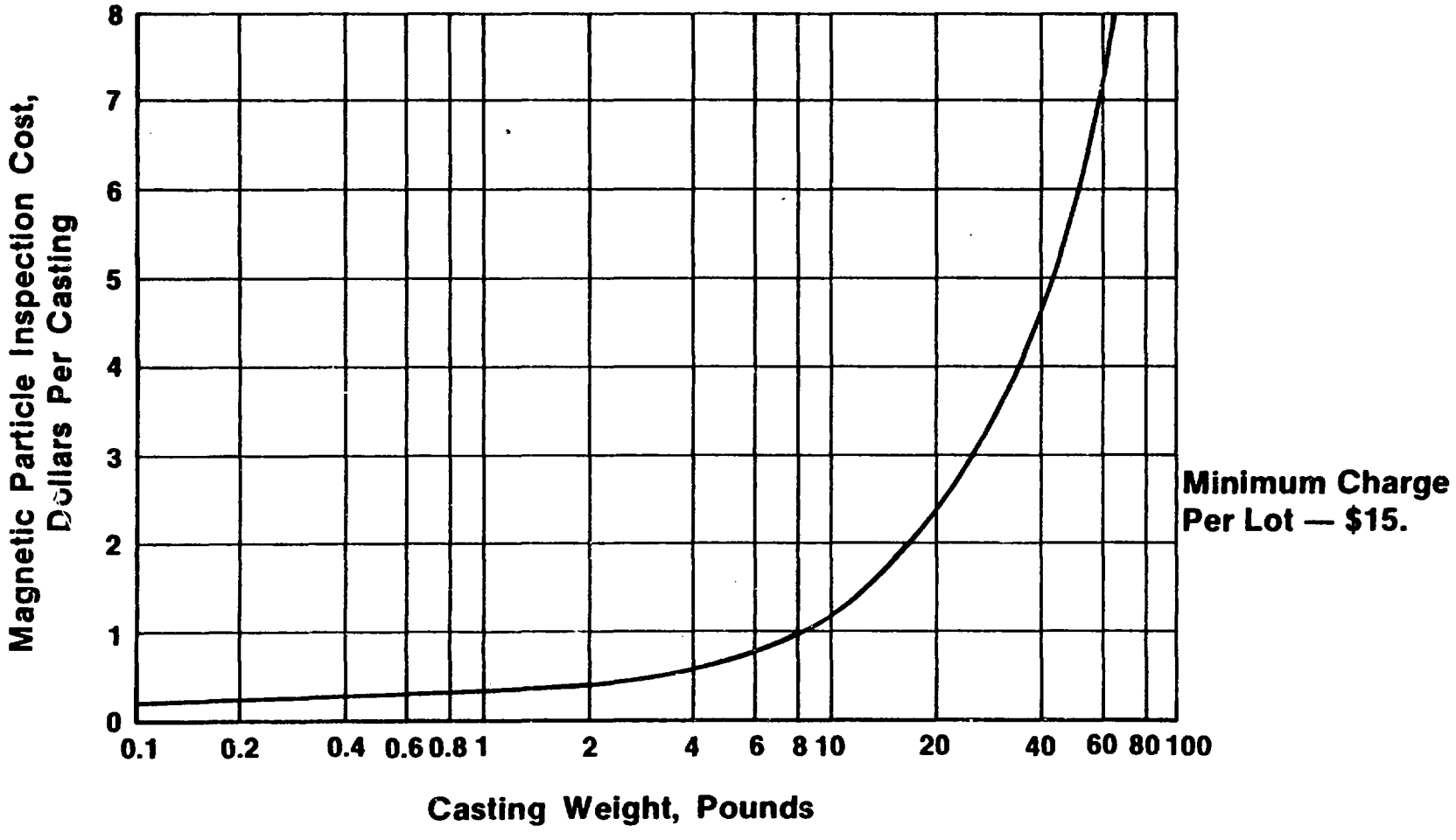



CED-TI&E-C-4


CASTING TEST, INSPECTION & EVALUATION COST
PENETRANT INSPECTION
BY COMMERCIAL LABORATORY
Minimum Charge
Per Lot $15.
Penetrant Inspection Cost,
Dollars Per Casting
0
1
2
3
4
5
6
7
8
0.1
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
60
80
100
Casting Weight, Pounds

CED-TI&E-C-5

# CASTING TEST, INSPECTION & EVALUATION
# MAGNETIC PARTICLE INSPECTION
# BY COMMERCIAL LABORATORY

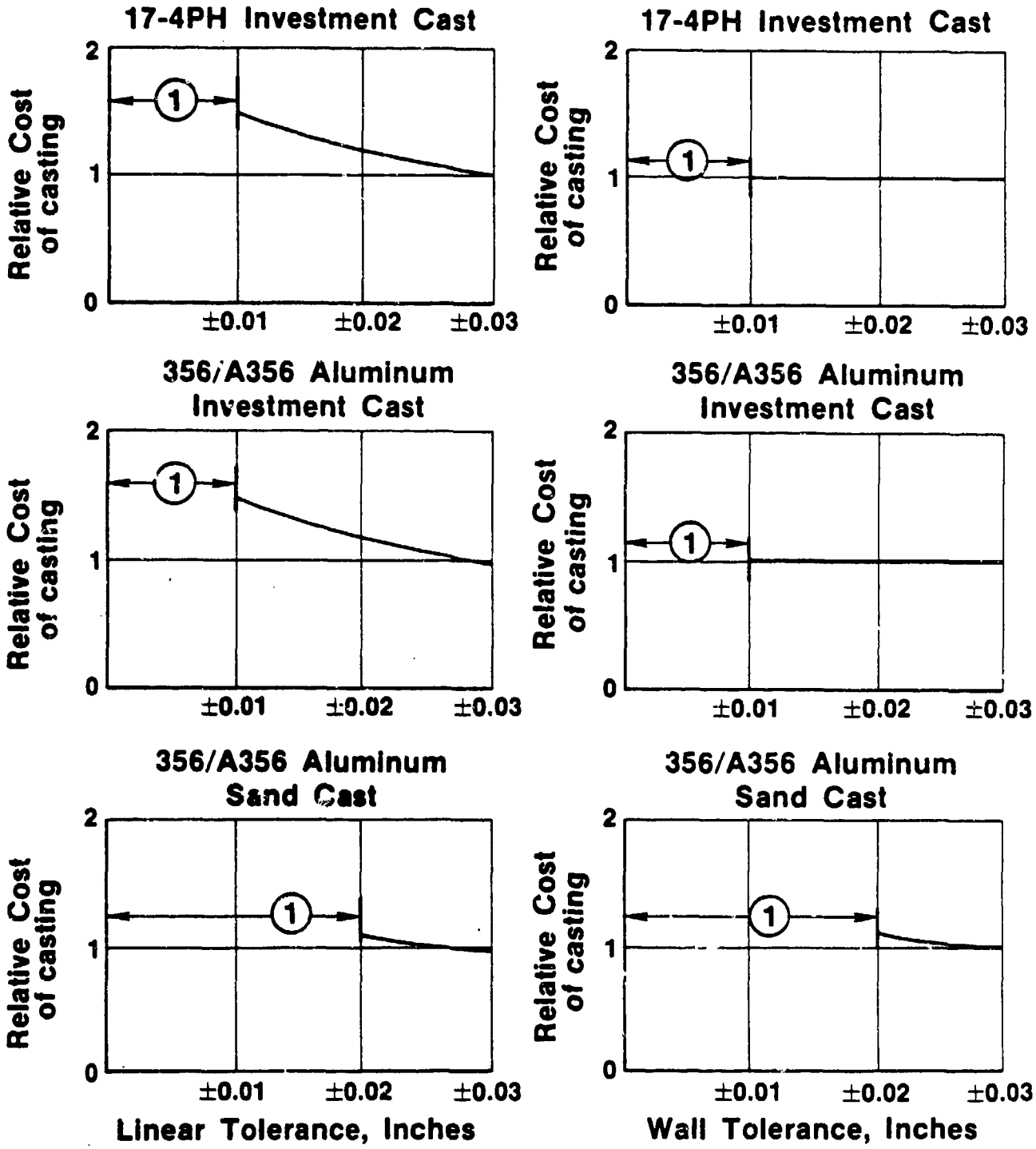



CED-TI&E-C-6



FTR450261000U
3 Jan 1983

# CASTING TOLERANCES COST-DRIVER EFFECT




① Impractical
② Based on a 7-Inch Linear Dimension

CDE-DICE-C-I

# X-RAY GRADE REQUIREMENT COST DRIVER EFFECT

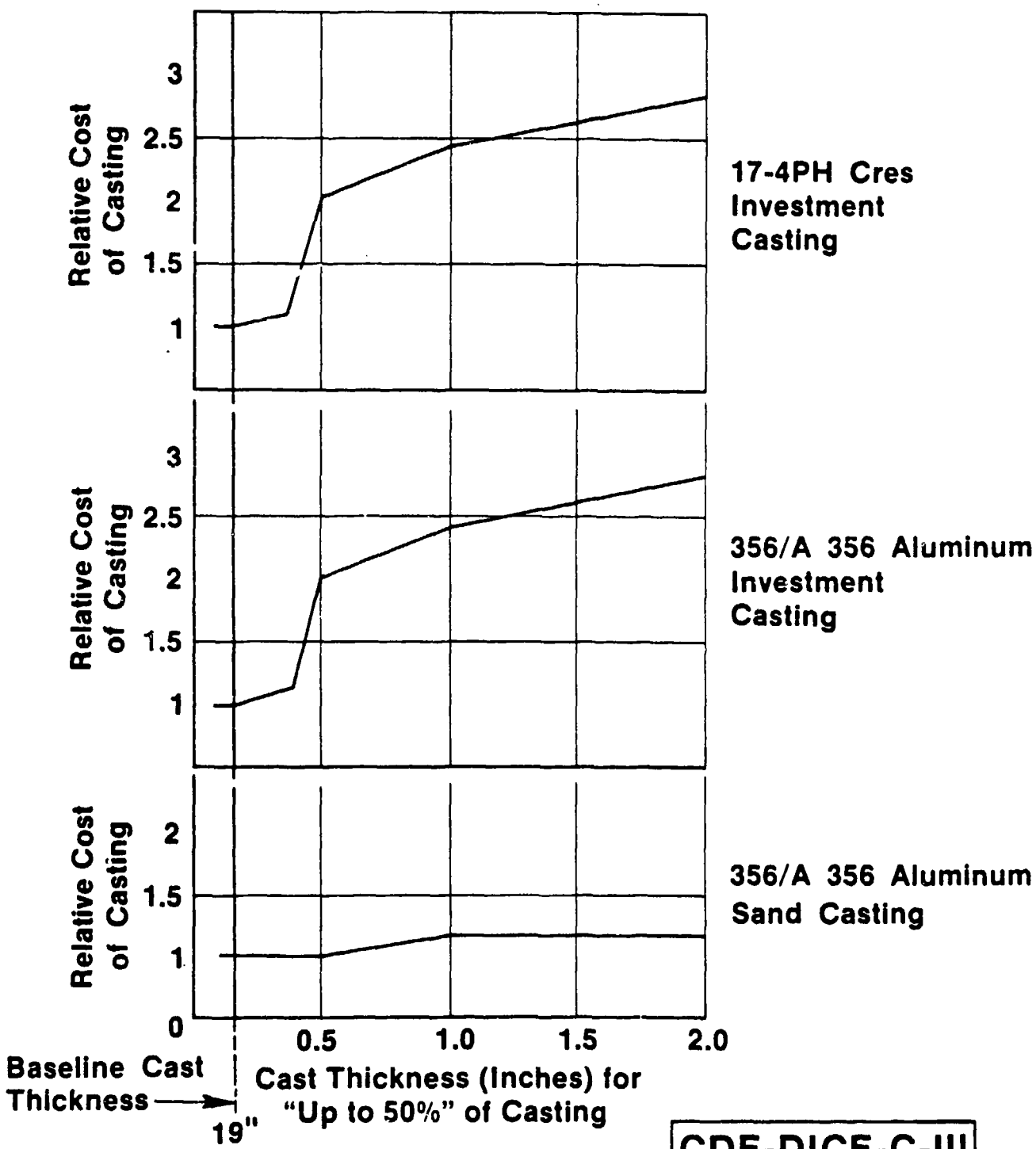
| CASTING MATERIAL & PROCESS | X—RAY GRADE | COST EFFECT |
|---|---|---|
| 356/A356 ALUMINUM SAND CAST | D OR C | BASE |
| | D OR C WITH 10% B | +15% |
| | D OR C WITH 50% B | +25% |
| | B | +50% |
| 356/A356 ALUMINUM INVESTMENT CAST | D OR C | BASE |
| | D OR C WITH 10% B | +10% |
| | D OR C WITH 50% B | +20% |
| | B | +50% |
| 17-4PH CRES INVESTMENT CAST | D OR C | BASE |
| | D OR C WITH 10% B | +20% |
| | D OR C WITH 50% B | +30% |
| | B | +60% |

NOTE: X-Ray Grade A is an Impractical Requirement for General or Local Areas of Casting.

CDE-DICE-C-II

# COST IMPACT OF CHANGE IN CAST THICKNESS

## COST-DRIVER EFFECT




CDE-DICE-C-III

# CAST SURFACE FINISH
# COST-DRIVER EFFECT

| Casting Surface | | Cost Effort | | | |
|---|---|---|---|---|---|
| Cast Surface Finish Designation | Equivalent Machine Finish - Micro Inches | 356/A356 Aluminum Sand Casting | | 356/A356 Aluminum & 17-4 Cres Investment Casting | |
| | | % of Surface | | % of Surface | |
| | | 10% | 50% | 10% | 50% |
| C-25 | 250 | Base | Base | Base | Base |
| C-20 | 200 | +10% | +20% | ↕ | ↕ |
| C-15 | 150 | +10% | (1) | | |
| C-12 | 125 | +10% | (1) | Base | Base |
| C-9 | 90 | (1) | (1) | (1) | (1) |
| C-6 | 63 | (1) | (1) | (1) | (1) |

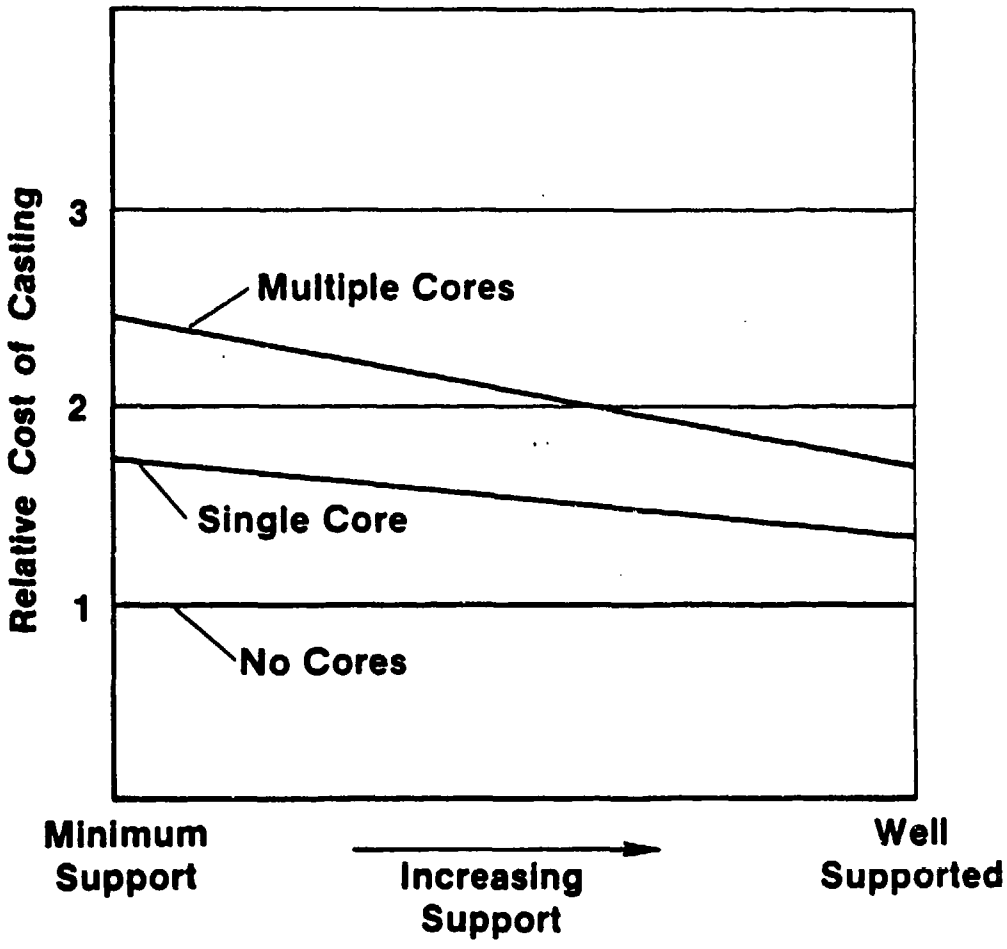
(1) Impractical



CDE-DICE-C-IV

# IMPACT OF CORES AND DEGREE OF CORE SUPPORT ON COST OF ALUMINUM SAND CASTINGS

## COST-DRIVER EFFECT

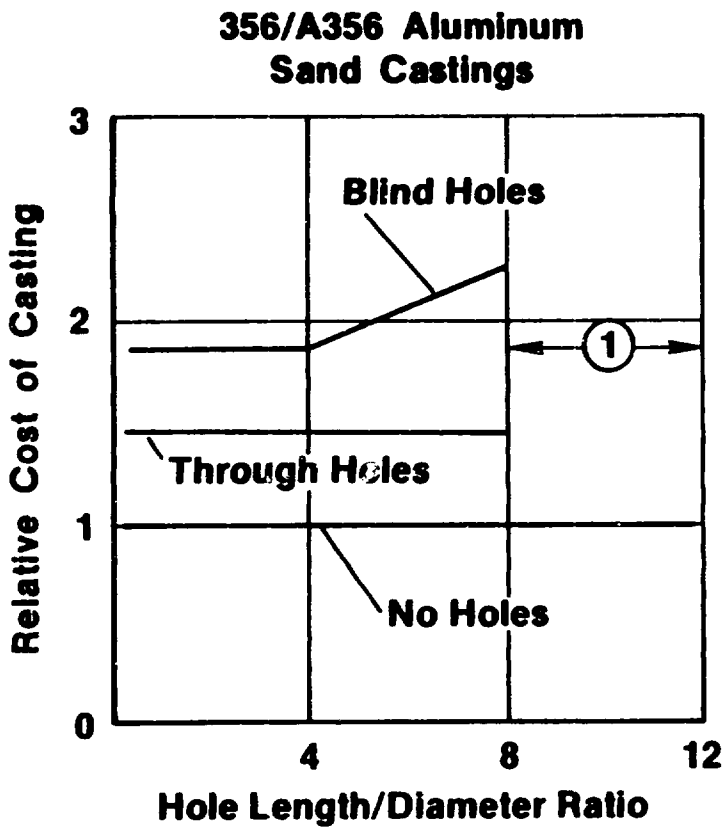


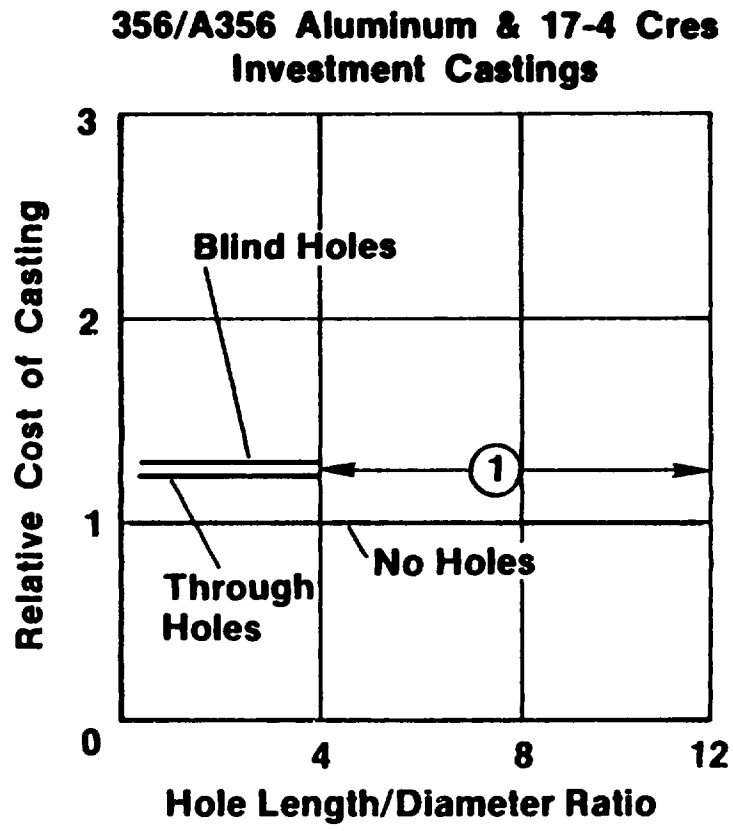



CDE-DICE-C-V

# EFFECT OF THROUGH & BLIND HOLES ON THE COST OF CASTINGS

## COST-DRIVER EFFECT




(1) Impractical

CDE-DICE-C-VI

FTR450261000U
3 Jan 1983

4.7.3.4 Ground Rules for Castings Section (including TI&E)

The following General and Detailed Ground Rules for the Castings Section were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats. These ground rules are identical to those in the MC/DG Casting Section 4.5.

4.7.3.4.1 General Ground Rules

The general ground rules are categorized under the following major groupings:

(a) Casting designs
(b) Materials
(c) Casting and machining
(d) Facilities
(e) Data generation - recurring costs (including TI&E)
(f) Castings - TI&E recurring costs
(g) Data generation - nonrecurring costs (including TI&E)
(h) Support function modifiers
(i) Test and evaluation of data.

(a) Casting Designs

(1) The casting designs selected will be representative of parts commonly required for both small and large aircraft. The parts will be selected such that a base part forms the foundation which the designer can modify as required to achieve the desired discrete part.
(2) The castings will be selected, where possible, to develop data for more than one casting method. The data thereby enables the designer, using the MC/DG, to determine the most cost-competitive casting process in trade-studies.
(3) The selected castings will adequately display in CED or CDE formats, the effect on cost of DICE (e.g., thin walls, core complexity, corner radii, and structural classification).

(b) Materials

(1) The alloys selected for the cast parts will be those commonly used in the industry to enable a uniform data base to be established. The materials included are:

- Aluminum
- Titanium
- Steel.

(c) Casting and Machining

(1) Only conventional casting processes, TI&E methods, and machining methods required to produce finished parts in the configurations selected will be considered. No emerging manufacturing methods will be evaluated.

(2) A production, in contrast to a prototype environment, will be assumed for the cast machined parts.

(3) To generate an effective data base for each selected part, a factory operational sequence utilized by the casting user will be established reflecting the most economical means of fabrication of the final part. This standardized sequence will be used by each team member to determine the part cost.

(4) Requirements for tooling to machine and inspect the various parts will be identified on the data collection forms.

(d) Facilities

(1) Only standard manufacturing and TI&E facilities, available to the airframe industry, will be considered.

(e) Data Generation - Recurring Costs

(1) Recurring cost data (standard man-hours) will be generated for the complete fabrication process and will, therefore, include all the hands-on direct factory labor operations from receipt of the raw casting through storage of part in readiness for assembly into the airframe, excluding bearings,

bushings, and threaded inserts. The data will also include the raw casting TI&E data.

(2) Raw casting data presented in the MC/DG formats shall include total raw casting costs including TI&E with mechanical property verification.

(3) Data will be generated separately for aluminum sand, aluminum investment, and steel investment castings. Data will be based on box volume using team companies' historical data.

(4) Raw casting part costs will be generated for each type of casting.

(5) The DICE elements will be treated as separate cost elements and, therefore, not included in the base-part cost, but will be displayed in CED or CDE formats.

(6) Recurring tooling costs (tool maintenance, tool planning, etc.) will not be included.

(7) The quantity for which the base part and the DICE costs will be determined is at unit 200. A lot release size of 25 will be applied.

(8) The data submitted to BCL will be the raw casting part cost (man-hours or dollars) plus the DICE incremental factors associated with the discrete casting design.

(9) In developing the cost data for parts, each participating company may utilize its own proprietary improvement curves.

(10) The part casting and DICE costs will be normalized by BCL to reflect an industry team average value.

(11) For proprietary reasons, business sensitive information employed at team member contributing companies will not be presented in the MC/DG.

(12) No data provided by any team member will be disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(f) Castings - TI&E Recurring Costs

(1) The general ground rules for castings (paragraphs 2, 6, 7, 9, 11, and 12) also apply to the casting TI&E. The following are added for casting TI&E.

(2) Recurring cost data will be generated for TI&E functions required from the supplier to receiving stores, including outside laboratories.

(3) TI&E cost data for the raw castings only will be included.

(4) Costs will be presented in 1980 dollars.

(5) CED and/or CDE formats will display the following TI&E costs and data:

- Penetrant inspection
- Radiographic inspection
- Magnetic particle inspection
- Mechanical properties verification
- Chemistry verification
- Dimensional inspection.

(6) TI&E cost data will be normalized by BCL to reflect an industry team average value.

(g) Data Generation - Nonrecurring Costs for Raw Castings and TI&E

(1) Tooling costs will be generated for each part type. TI&E fixture costs will be the responsibility of the user company where applicable.

(2) The cost of production tooling will be restricted to contract or project tools only for presentation in the MC/DG.

(3) First article TI&E cost will be generated and displayed as part of the nonrecurring tooling cost.

(4) Nonrecurring tooling costs (NRTC) generated by the team companies will be normalized by BCL for presentation in the MC/DG.

(h) Support Function Modifiers

(1) Additional effort other than factory labor and TI&E, i.e., planning and tool maintenance, will be excluded from the part cost data supplied to BCL. Other modifiers may be included later by the MC/DG users at airframe companies.

(i) Test and Evaluation of Data

(1) Test and confirmation of the formats and integrated data will be accomplished by one team member. Each of the remaining team members will be provided with the evaluation. Any anomalies will be resolved and modifications incorporated as appropriate.

4.7.3.4.2 Detailed Ground Rules

The detailed ground rules are categorized under the following major groups:

(a) Casting designs
(b) Materials
(c) Classification
(d) Data generation - recurring costs
(e) TI&E functions.

(a) Casting Designs

(1) Each team member will review applicable casting designs and tabulate required data on the data collection sheets developed by the team.
(2) Selected typical designs will be utilized for determination of user-associated costs (e.g., machining and finishing).
(3) The castings analyzed by each team member will be classified by complexity type. This classification will be designated on the data collection form submitted to BCL.

Each team member company will submit to BCL a definition or a drawing or sketch illustrating their proposed understanding of these classifications.

(b) Materials

(1) The materials and processes selected for castings are:

- Aluminum
  - A356 per MIL-A-21180 or company equivalent specification (sand or investment)
  - 356 or A356 per QQ-A-601 (sand castings)
  - 357 per MIL-A-21180 (sand castings)
- Steel
  - 17-4PH CRES per AMS-5342, 5343, and 5344 or company equivalent specification
- Titanium
  - Ti-6Al-4V Cond A (vacuum cast, investment or rammed graphite).

(c) Classification

(1) The basic use classification (Class I or II) shall be reported for each casting.

(2) The casting quality shall comply with MIL-C-6021 or equivalent user company specification for X-ray grade.

(3) The radiographic standard grade (A, B, C, or D) basis for each casting shall be reported. Special testing (e.g., static tests) used to complement inspection shall be identified.

(d) Data Generation - Recurring Costs

(1) Data indicated on the data collection sheet will be gathered, as available, for the raw casting. TI&E costs associated with the raw casting will be established separately.

(2) Machining (including cleaning and protective coatings) will be reported separately for typical parts utilizing standards and learning (improvement) curves, if applicable. TI&E costs for the user operations will not be included as a part of this task.

(3) Machining cost data will be developed for the following basic machining parameters:

(a) Counter-bore and face-hub

(b) Drilled holes, drilled and reamed holes, drilled and spot-faced holes

(c) Circular-flange facing (lathe), flat-faced (mill)

(d) Straddle-mill and drill-clevis fittings.

(4) Available cost data for titanium castings obtained from suppliers by BCL will be analyzed and formatted.

(e) TI&E Functions

(1) The following are typical TI&E operations that will be evaluated:

- Chemistry
- Mechanical properties
  - Separately cast test bars
  - Coupons from castings (prolongation)
  - Dissected castings
- Dimensional
- Radiographic
- Penetrant/magnetic
- Surface finish
- Pressure test
- Static test (proof of design).

### 4.7.4 TI&E for Forgings

This section contains format selection aids and data to determine the TI&E manufacturing man-hours, examples of how the data are utilized in airframe design and a set of formats generated. These formats are cost-estimating data (CED).

#### 4.7.4.1 Format Selection Aid

A format selection aid (Figure 4.7.4-1) provides the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design.

# FORMAT SELECTION AID
# TEST, INSPECTION & EVALUATION

## FORGINGS

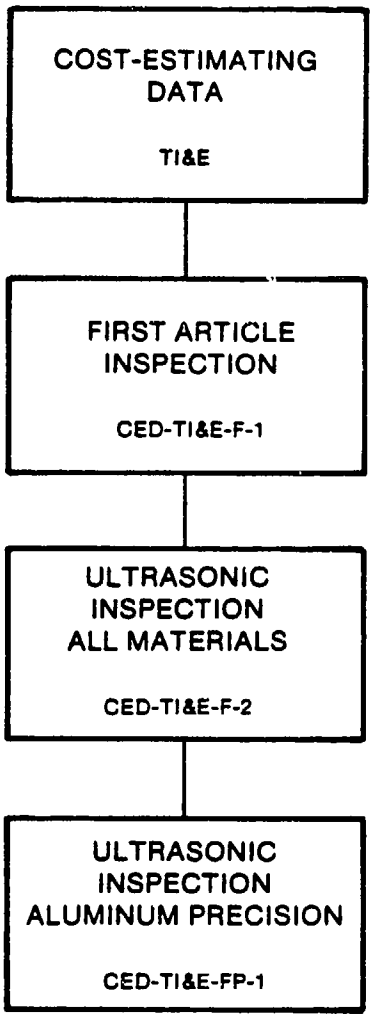



FIGURE 4.7.4-1

### 4.7.4.2 Example of Utilization

These examples demonstrate how the data generated are utilized on a specific design problems. The example shows how to identify applicable formats, how to extract data from the formats, and provides a discussion on how the data are used to determine the part cost in man-hours or dollars. The MC/DG cost worksheet (Table 3-3) can be used to record the cost data for easy reference and to determine the total program cost. The forging cost worksheet included as Table 4.7.4-1 has been utilized for this example.

#### 4.7.4.2.1 Utilization Example for Titanium Hand Forging

Problem Statement

Determine the cost, in 1982 dollars per part, for the titanium 6Al-4V hand forging shown in the sketch below. The dimensions are as shown in the sketch, and the buy quantity is ten pieces. The cost of test, inspection and evaluation (TI&E) is to be included.

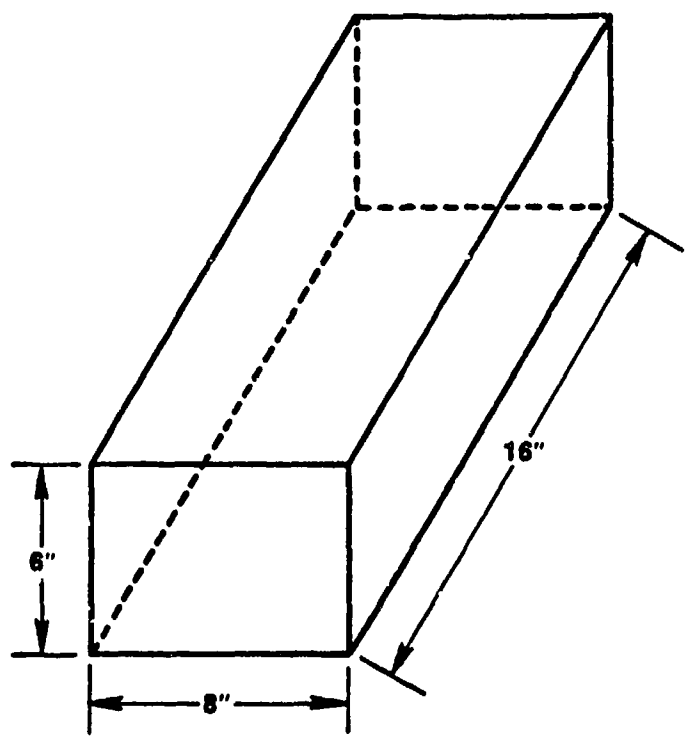



FIGURE 4.7.4-2. PART ANALYZED

Procedure

The following procedure is used to determine the forging cost.

1. Utilize the Format Selection Aid for Forgings Cost-Estimating Data (Figure 4.7.4-1).

2. Determine the format to use. In this case, Format CED-FH-1 (Figure 4.7.4-3) is required.

3. Study the format to determine the parameters and conditions necessary for its use and relate these to the part. For CED-FH-1, the material and forging type are required.

4. From CED-FH-1, choose the appropriate cost equation and read the specific weight and cost per pound from the chart on the format.

   - The equation for hand forgings is to be used.
   - The specific weight is 0.16 lb/in.$^3$, and the cost per pound is $30.
   - Substituting these values and the part dimensions into the equation yields:

     W x H x L x Specific Weight x Cost x Inflation Factor = Cost/Part

     8 in. x 6 in. x 16 in. x 0.16 lb/in.$^3$ x $30/lb x 1 = $3690/part.

5. Utilize the Format Selection Aid for Test, Inspection, and Evaluation (TI&E) of Forgings (Fig. 4.7.4-1).

6. Determine the format to use. In this case, Format CED-TI&E-F-1 (Figure 4.7.4-4) is required.

7. Study the format to determine necessary parameters and conditions. For CED-TI&E-F-1, forging type and inspection type are required.

8. From CED-TI&E-F-1, read the TI&E cost.

   - TI&E cost per lot is $300.
   - Divide the cost per lot by the order quantity (10) and multiply by the inflation factor (in this case 1) to determine cost per part: ($300/10) x 1 = $30 per part.

9. Add TI&E cost to forging cost to obtain total cost per part: $3690 + $30 = $3720 per part.

# HAND/RING FORGINGS
# BASE PART COST

FTR450261000U
3 Jan 1983

**TO DETERMINE FORGING COST:**

**HAND FORGING**

**W × H × L × SPECIFIC WEIGHT × COST × INFLATION FACTOR**

**RING FORGING**

**0.785 ($OD^2$ - $ID^2$) THICKNESS × SPECIFIC WEIGHT × COST × INFLATION ACTOR**

**NOTE: ALL DIMENSIONS IN INCHES. INFLATION FACTOR TO BE SUPPLIED BY USER COMPANIES.**

| MATERIAL | SPECIFIC WEIGHT POUNDS PER CUBIC INCH | COST, 1982 DOLLARS PER POUND |
|---|---|---|
| ALUMINUM<br>7075-F<br>-T6<br>-T652<br>-T7352 | 0.10 | $3 |
| TITANIUM<br>Ti6Al-4V | 0.16 | $30 |
| LOW ALLOY STEEL<br>4340 | 0.28 | $3 |
| PH CRES<br>15-5PH | 0.28 | $7 |

FIGURE 4.7.4-3. FORMAT USED IN EXAMPLE

**CED-FH-1**

# ALUMINUM, TITANIUM, STEEL, CRES FORGINGS TEST, INSPECTION, AND EVALUATION

| INSPECTION | HAND AND ROLLED RING FORGINGS | BLOCKER, CONVENTIONAL & PRECISION FORGINGS |
|---|---|---|
| FIRST ARTICLE (NONRECURRING) | NOT APPLICABLE | COST OF ONE (1) FORGING + |
| | | PLAN AREA — 1982 $ |
| | | 100 SQ. IN. — 300 |
| | | 101-500 SQ. IN — 400 |
| | | 501-1,000 SQ. IN. — 500 |
| | | 1,001 up — 600 |
| PRODUCTION | $300/LOT | COST OF ONE (1) FORGING + $300 PER LOT. |

NOTE: COSTS IN 1982 DOLLARS ARE FOR BOTH SUPPLIER AND USER. ULTRASONIC INSPECTION COSTS TO BE ADDED.

FIGURE 4.7.4-4. FORMAT USED IN EXAMPLE

CED-TI&E-F-I

TABLE 4.7.4-1

**FORGING COST WORKSHEET**

TITLE: HAND FORGING DESIGN QUANTITY: 50 LOT QUANTITY: 10 DESIGNER: JFW DATE: 6/20/12

| TYPE | MATERIAL | HAND/RING | BLOCKER/CONV. | CONV./PRECISION | PRECISION | TEST, INSP. & EVALUATION |
|---|---|---|---|---|---|---|
| Hand ✓<br>Ring ____<br>Blocker ____<br>Conv. ____<br>Precision ____ | Aluminum ____<br>TI6Al-4V ✓<br>4340<br>Air ____<br>Vacuum ____<br>PH Cres<br>15-5 ____<br>13-8 ____ | Size<br>L 16 OD ____<br>W 8 ID ____<br>T 16 T ____<br>Weight 123 Lb<br>Base Cost<br>$ 30 /Lb | Weight ____ Lb<br>Base Cost<br>$ ____ /Lb<br>Setup Cost<br>$ ____ /Lot<br>Size L ____<br>W ____ H ____<br>Die Factor ____ | Category<br>A ____ B ____<br>C ____ D ____<br>Plan Area<br>____ Sq. In.<br>Buy-Quantity Factor ____ | Base Cost<br>$ ____ Ea.<br>Setup Cost<br>$ ____ Ea.<br>DICE Factor<br>Rec. ____<br>Nonrec. ____ | First Article Cost<br>One Forging + $ ____ = $ ____<br>Production Cost/Lot<br>One Forging + $300 = $ 300<br>Ultrasonic Insp. $ ____ Each<br>Inflation Factor 1.0 |

**RECURRING COST**

**Hand/Ring Forging**

Cost/Part = Weight × Base Cost × Inflation Factor

= 123 Lbs × $ 30 /Lb × 1.0 = $ 3690 Each

**Blocker Forging**

Cost/Part = [Weight × Base Cost × 0.8 × Buy Qty. Factor + Setup/Lot / Buy Qty.] Inflation Factor

= [____ Lb × $ ____ /Lb × 0.8 × ____ + $ ____ / ( ) /Lot] ____

= $ ____ Each

**Conventional Forging**

Cost/Part = [Weight × Base Cost × Buy Qty. Factor + Setup/Lot / Buy Qty.] Inflation Factor

= [____ Lb × $ ____ Lb × ____ + $ ____ / ( ) /Lot] ____

= $ ____ Each

**Precision Forging**

Cost/Part = [Base Cost × Rec. DICE Factor × Buy Qty. Factor + Setup] Inflation Factor

= $ [____ Each × ____ × ____ + $ ____ Each] ____

= $ ____ Each

**NONRECURRING COST**

**Blocker / Conventional Forging**

Tool Cost = (L + 12")(W + 12")(H + 14") Die Factor × Inflation Factor

= ( ____ + 12") × ( ____ + 12") × ( ____ + 14") × ____ × ____

= $ ____

**Precision Forging**

Tool Cost = Base Tool Cost × Nonrec. DICE Factor × Inflation Factor

= ____ × ____ × $ ____

= $ ____

**Cost Summary**

Program Cost = Cost/Part × Design Quantity + Tool Cost + First Article T&E Cost + Prod T&E Cost/Lot × Design Qty. / Lot Qty.

= $ 3690 × 50 + 0 NA + 0 NA + 0 300 × ( 50 / 10 )

= $ 186,000 Total Cost/Part = Program Cost / Design Qty. = $ 3720 Each

### 4.7.4.2.2 Utilization Example for Aluminum Rolled Ring Forging

**Problem Statement**

Determine the cost, in 1982 dollars per part, for the 7075-T73 aluminum rolled-ring forging shown in the sketch below. The cost of test, inspection, and evaluation (TI&E) is to be included in the cost of the forging. The dimensions are as shown in the sketch, and the order quantity is eight pieces.

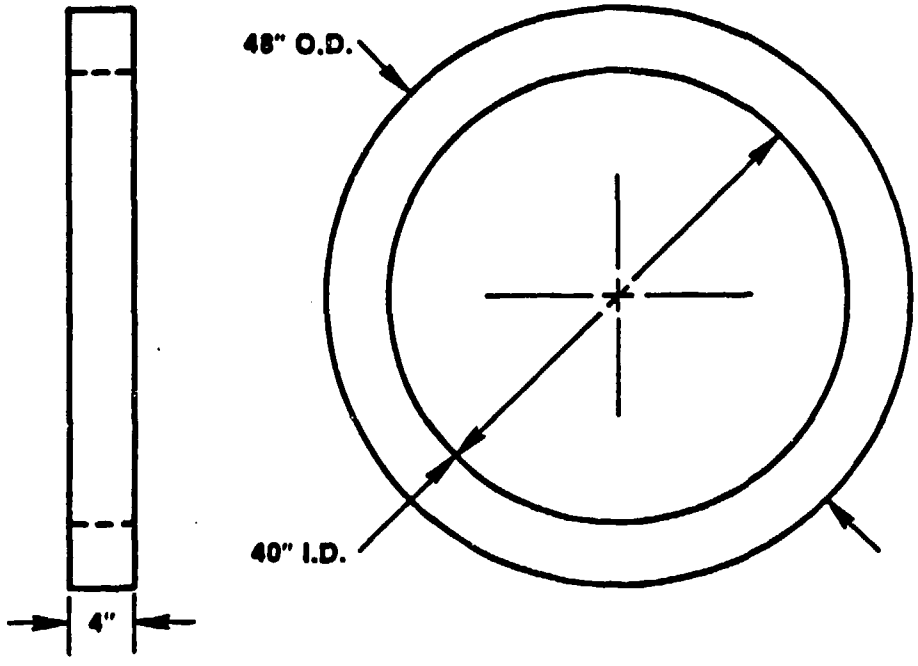



FIGURE 4.7.4-5. PART ANALYZED

**Procedure**

The following procedure is used to determine the forging cost.

1. Utilize the Format Selection Aid for Forgings Cost-Estimating Data (Figure 4.7.4-1).
2. Determine the format to use. In this case, Format CED-FH-1 (Figure 4.7.4-6) is required.
3. Study the format to determine the necessary parameters and conditions. For CED-FH-1, the material and forging type are required.
4. From CED-FH-1, choose the appropriate cost equation and read the specific weight and cost per pound from the chart on the format.
   - The equation for rolled-ring forgings is to be used.

- The specific weight is 0.10 lb/in.$^3$, and the cost per pound is $3.
- Substituting these values and the part dimensions into the equation yields:

  0.785 (OD-ID) x Thickness x Specific Weight x Cost x Inflation Factor = Cost/Part

  0.785 (48 in. - 40 in.) x 4 in. x 0.1 lb/in.$^3$ x $3/lb x 1 = $663/part.

5. Utilize the Format Selection Aid for Test, Inspection, and Evaluation (TI&E) of Forgings (Figure 4.7.4-1).
6. Determine the format to use. In this case, Format CED-TI&E-F-1 (Figure 4.7.4-7) is required.
7. Study the format to determine necessary parameters and conditions. For CED-TI&E-F-1, forging type and inspection type are required.
8. From CED-TI&E-F-1, read the TI&E cost.
   - TI&E cost per lot is $300.
   - Divide cost per lot by order quantity (8) and multiply by the inflation factor (in this case, 1) to determine cost per part: ($300/8) x 1 = $38 per part.
9. Add TI&E cost to forging cost to obtain total cost per part: $663 + 38 = $701 per part.

# HAND/RING FORGINGS BASE PART COST

**TO DETERMINE FORGING COST:**

**HAND FORGING**

**W × H × L × SPECIFIC WEIGHT × COST × INFLATION FACTOR**

**RING FORGING**

**0.785 ($OD^2$ - $ID^2$) THICKNESS × SPECIFIC WEIGHT × COST × INFLATION FACTOR**

**NOTE: ALL DIMENSIONS IN INCHES. INFLATION FACTOR TO BE SUPPLIED BY USER COMPANIES.**

| MATERIAL | SPECIFIC WEIGHT POUNDS PER CUBIC INCH | COST, 1982 DOLLARS PER POUND |
|---|---|---|
| ALUMINUM<br>7075-F<br>-T6<br>-T652<br>-T7352 | 0.10 | $3 |
| TITANIUM<br>TI6Al-4V | 0.16 | $30 |
| LOW ALLOY STEEL<br>4340 | 0.28 | $3 |
| PH CRES<br>15-5PH | 0.28 | $7 |

FIGURE 4.7.4-6. FORMAT USED IN EXAMPLE

CED-FH-1

# ALUMINUM, TITANIUM, STEEL, CRES FORGINGS TEST, INSPECTION, AND EVALUATION

| INSPECTION | HAND AND ROLLED RING FORGINGS | BLOCKER, CONVENTIONAL & PRECISION FORGINGS |
|---|---|---|
| FIRST ARTICLE (NONRECURRING) | NOT APPLICABLE | COST OF ONE (1) FORGING +<br><br>PLAN AREA — 1982 $<br>100 SQ. IN. — 300<br>101-500 SQ. IN — 400<br>501-1,000 SQ. IN. — 500<br>1,001 up — 600 |
| PRODUCTION | $300/LOT | COST OF ONE (1) FORGING + $300 PER LOT. |

NOTE: COSTS IN 1982 DOLLARS ARE FOR BOTH SUPPLIER AND USER. ULTRASONIC INSPECTION COSTS TO BE ADDED.

FIGURE 4.7.4-7. FORMAT USED IN EXAMPLE

CED-TI&E-F-I

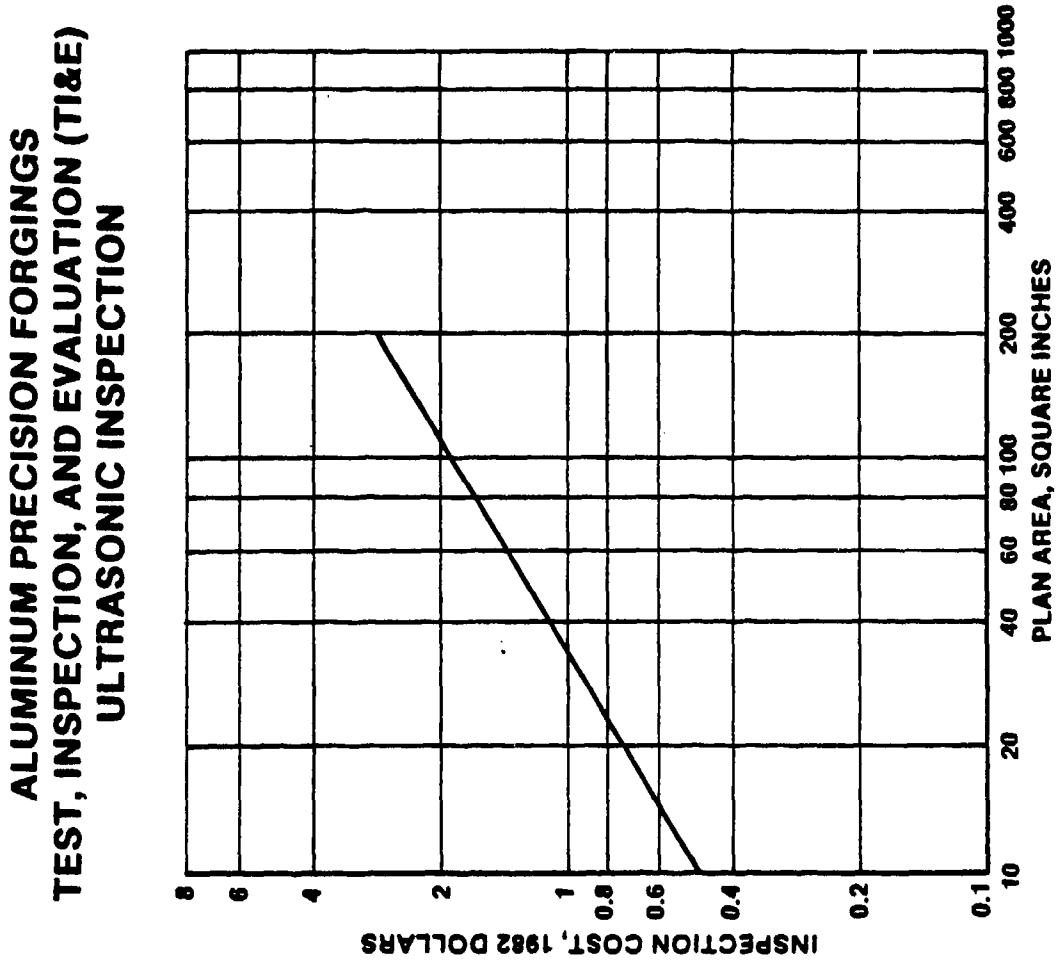
4.7.4.3 Parts Analyzed

The forgings analyzed to determine the TI&E data are reviewed in Section 4.6 "Forgings".

4.7.4.4 TI&E Data for Forgings

The TI&E data for forgings are presented to the designer on the following pages. The formats provide cost-estimating data (CED).

CED-TI&E-FP-1

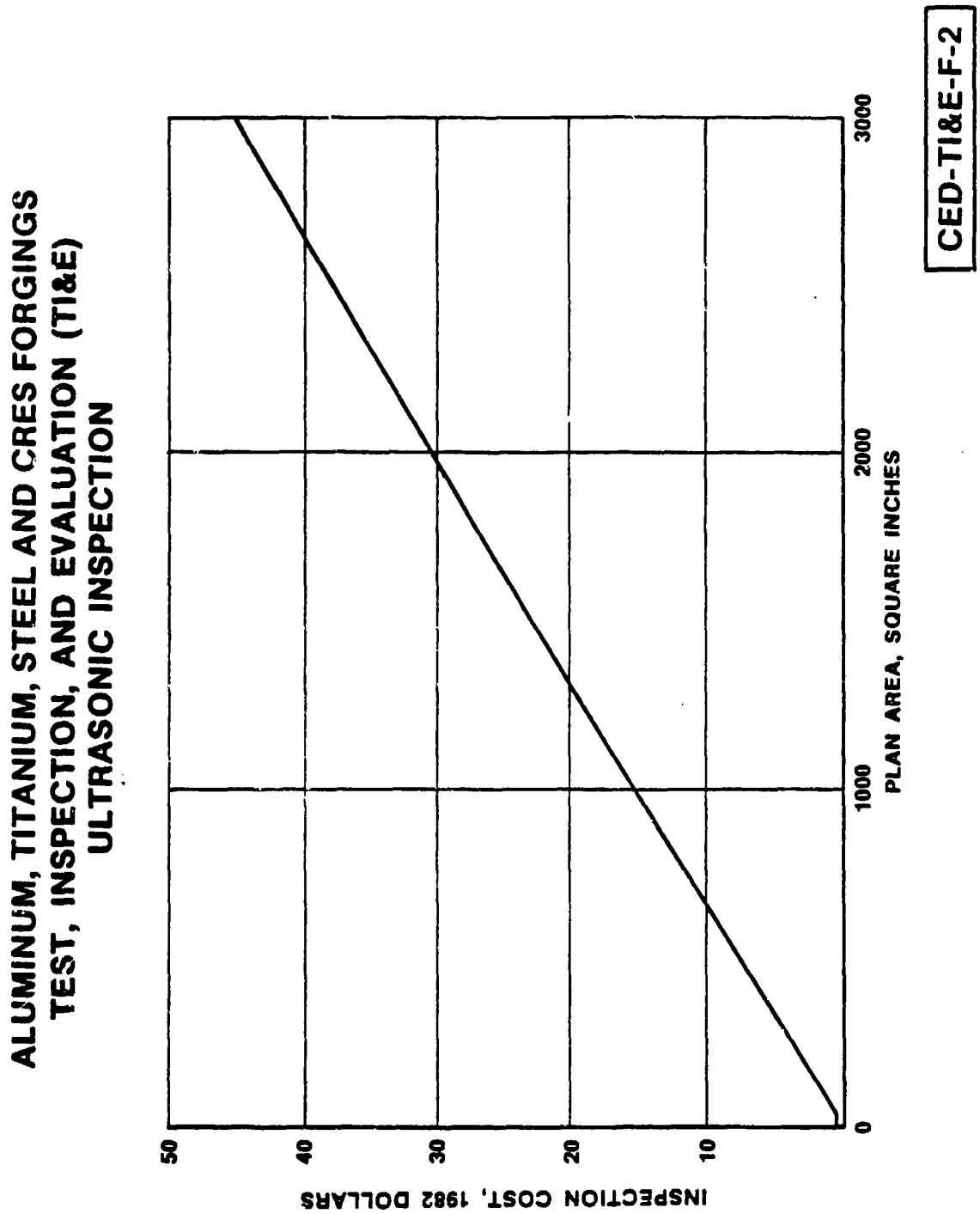

ALUMINUM PRECISION FORGINGS
TEST, INSPECTION, AND EVALUATION (TI&E)
ULTRASONIC INSPECTION
INSPECTION COST, 1982 DOLLARS
8
6
4
2
1
0.8
0.6
0.4
0.2
0.1
10
20
40
60
80
100
200
400
600
800
1000
PLAN AREA, SQUARE INCHES

# ALUMINUM, TITANIUM, STEEL,CRES FORGINGS TEST, INSPECTION, AND EVALUATION

| INSPECTION | HAND AND ROLLED RING FORGINGS | BLOCKER, CONVENTIONAL & PRECISION FORGINGS |
|---|---|---|
| FIRST ARTICLE (NONRECURRING) | NOT APPLICABLE | COST OF ONE (1) FORGING +<br><br>PLAN AREA — 1982 $<br>100 SQ. IN. — 300<br>101-500 SQ. IN — 400<br>501-1,000 SQ. IN. — 500<br>1,001 up — 600 |
| PRODUCTION | $300/LOT | COST OF ONE (1) FORGING + $300 PER LOT. |

NOTE: COSTS IN 1982 DOLLARS ARE FOR BOTH SUPPLIER AND USER. ULTRASONIC INSPECTION COSTS TO BE ADDED.

CED-TI&E-F-I


ALUMINUM, TITANIUM, STEEL AND CRES FORGINGS
TEST, INSPECTION, AND EVALUATION (TI&E)
ULTRASONIC INSPECTION
INSPECTION COST, 1982 DOLLARS
50
40
30
20
10
0
1000
2000
3000
PLAN AREA, SQUARE INCHES
CED-TI&E-F-2

4.6.4.5 Ground Rules for TI&E - Forging Section

The following General and Detailed Ground Rules for the Forging Section were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

4.7.4.5.1 General Ground Rules

The General Ground Rules are categorized under the following major groups:

(a) Forging Types
(b) Materials
(c) Forging and Applicable Machining (Limited)
(d) Machining
(e) Facilities
(f) Data Generation - Recurring Costs (including Forging TI&E)
(g) Forging TI&E Recurring Costs
(h) Data Generation - Nonrecurring Costs (including Forging TI&E)
(i) Support Function Modifiers
(j) Test and Evaluation of Data.

(a) Forging Types

(1) The forging types selected will be representative of parts commonly required for both small and large aircraft. The parts will be selected such that a base part forms the foundation from which the desired discrete part can be fabricated.
(2) The forgings will be selected, where possible, to develop data for more than one forging method. The data thereby enable the designer, using the MC/DG, to perform a trade-off study to evolve the most cost-effective discrete part.
(3) The selected forgings will adequately display, by CED and CDE formats, the effect on cost of DICE.

(b) Materials

(1) The materials selected for the forged parts will be those commonly used in the industry to enable a uniform data base to be established. The materials included are:

- Aluminum
- Titanium
- Steel.

(c) Forgings and Machining

(1) Only conventional forging processes and TI&E methods will be considered. No emerging manufacturing methods will be evaluated.

(2) A production, in contrast to a prototype environment, will be assumed for the forged parts.

(3) To generate an effective data base for each selected part, a factory operational sequence utilized by the user will be established reflecting the most economical means of fabrication of the final part. This standardized sequence will be used by each team member to determine the part cost.

(d) Machining

(1) Limited machining data, as reflected in the MC/DG section on machining of castings, will be utilized for the forging section.

(e) Facilities

(1) Only standard manufacturing and TI&E facilities, will be considered.

(f) Data Generation - Recurring Costs

(1) Recurring cost data will be generated for the raw forging types being considered, and will include TI&E and mechanical property verification.

(2) Data will be generated separately for aluminum blocker, conventional, and precision forgings and titanium and steel blocker, and conventional forgings. Data to be based on plan area using historical data of the team airframe companies. Hand and ring forging cost methods will be developed.

(3) The DICE elements will be treated as separate cost elements, and therefore, not included in the base part cost, but will be displayed using CED and CDE formats.

(4) In-house recurring tooling costs (tool maintenance, tool planning, etc.) will not be included.

(5) The quantity for which the base part and the DICE costs will be determined is at unit 200. A lot release size of 25 will be applied.

(6) The data submitted to BCL will be the raw forging part cost (dollars) plus the DICE incremental factors associated with the discrete forging design.

(7) In developing the cost data for parts, each participating company may utilize its own proprietary improvement curves.

(8) The base part and DICE costs will be normalized by BCL to reflect an industry average value.

(9) For proprietary reasons, business sensitive information employed at team member contributing companies to determine the data, will not be presented in the MC/DG.

(10) No data provided by any team member will be disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(g) Forging - TI&E Recurring Costs

(1) The applicable ground rules for data generation for forgings will be applied to the TI&E recurring cost.

(2) Recurring cost data will be generated for TI&E functions required from the supplier to receiving stores, including outside laboratories.

(3) TI&E cost data for the raw forging only will be included.

(4) Costs will be presented in 1982 dollars.

(5) CED and/or CDE formats will display the following TI&E costs and data, when applicable, to provide meaningful cost data to the designer:

- Penetrant Inspection
- Ultrasonic Inspection
- Magnetic Particle Inspection
- Mechanical Properties Verification
- Chemistry Verification
- Dimensional Inspection.

(6) TI&E cost data will be normalized by BCL to reflect an industry team average value.

(h) Data Generation - Nonrecurring Costs for Raw Forgings and TI&E

(1) Tooling costs will be generated for each part type. TI&E fixture costs will be the responsibility of the user company where applicable.

(2) The cost of production tooling will be restricted to contract or project tools only for presentation in the MC/DG.

(3) First article TI&E cost will be generated and displayed as part of the nonrecurring tooling cost.

(4) Nonrecurring tooling costs (NRTC) generated by the team companies will be normalized by BCL for presentation in the MC/DG.

(i) Support Function Modifiers

(1) Additional effort other than factory labor and TI&E, i.e., planning and tool maintenance, will be excluded from the part cost data supplied to BCL. Other modifiers may be included later by the MC/DG users at airframe companies.

(j) Test and Evaluation of Data

(1) Test and confirmation of the formats and integrated data will be accomplished by one of the MC/DG team members. Each of the remaining team members will be provided with the evaluation. Any anomalies will be resolved and modifications incorporated as appropriate.

4.7.4.5.2 Detailed Ground Rules

The detailed ground rules are categorized under the following major groups:

(a) Forging Types
(b) Materials
(c) Data Generation - Recurring Costs
(d) Data Generation - Nonrecurring Costs
(e) TI&E Functions.

(a) Forging Types

(1) Each team member will review applicable forging designs and tabulate required data on the data collection sheets developed by the team.
(2) Selected typical designs will be utilized for determination of user-associated costs (e.g., machining).
(3) The forgings analyzed by each team member will be classified by material and type. This classification will be designated on the data collection form submitted to BCL. Each team member company will submit drawings or sketches to BCL illustrating their understanding of these forging types.

(b) Materials

(1) The materials and processes selected for the following forging types are:

- Aluminum
  - 7075 or equivalent hand, ring, blocker, conventional die, and precision forgings.

- Titanium
  - Ti-6Al-4V annealed hand, ring, blocker, and conventional forging.
- Steel
  - 4340 or equivalent hand, ring, blocker and conventional forging.

(c) Data Generation - Recurring Costs

(1) Data indicated on the data collection sheet will be gathered, as available, for the raw forging. TI&E costs associated with the raw forging will be established separately.

(2) Machining cost data previously developed for castings for the basic machining parameters listed below, will be reviewed for applicability to forgings. TI&E costs for the user operations will not be included as a part of this task.

(a) Counter-bore and face-hub

(b) Drilled holes, drilled and reamed holes, drilled and spot-faced holes

(c) Circular-flange facing (lathe), flat-faced (mill)

(d) Stradle-mill and drill-clevis fittings.

(d) Data generation - Nonrecurring Costs for Raw Forgings and TI&E

(1) Tooling costs will be generated for each part type. TI&E fixture costs will be the responsibility of the user company where applicable.

(e) TI&E Functions

(1) The following are typical TI&E operations that will be evaluated for cost impact:

- Chemistry

- Mechanical Properties
  - Separate test bars
  - Coupons from forgings (prolongation)
  - Dissected forgings
- Dimensional
- Ultrasonic
- Penetrant/Magnetic.

## 4.7.5 TI&E for Machining

### 4.7.5.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine TI&E cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide cost-driver effects (CDE) for qualitative guidance to the lowest cost and cost-estimating data (CED) in man-hours for conducting trade-studies.

# FORMAT SELECTION AID
# TEST, INSPECTION AND EVALUATION (TI&E)
# MACHINED PARTS

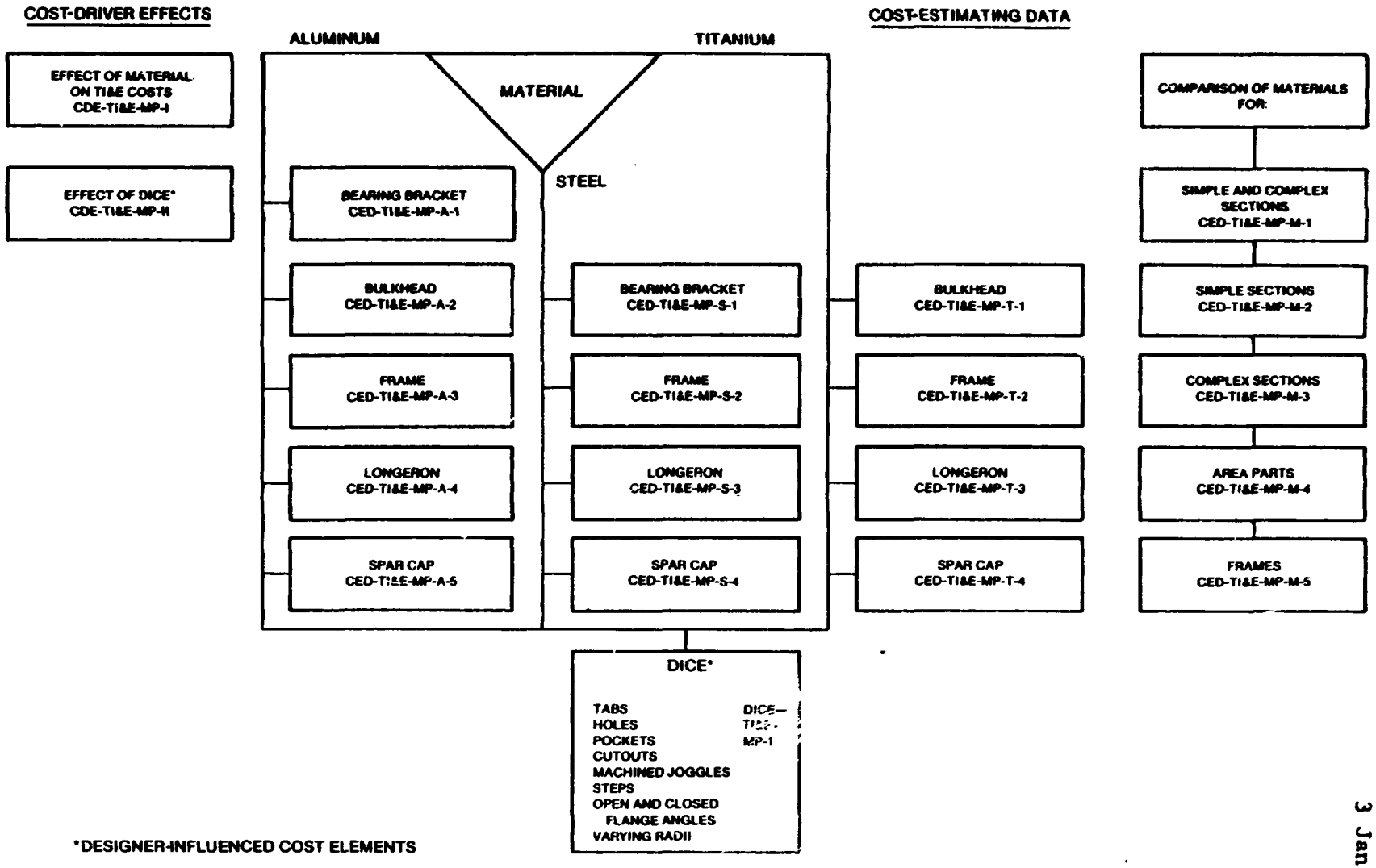



FIGURE 4.7.5-1

### 4.7.5.2 Example of Utilization

#### 4.7.5.2.1 Utilization Example for Aluminum Frame

**Problem Statement**

Determine the test, inspection, and evaluation (TI&E) cost (man-hours) of an aluminum (2024) frame with dimensions as shown in Figure 4.7.5-2.

**Procedure**

The procedure to determine the TI&E cost of the aluminum frame is presented below:

(1) Utilize Format Selection Aid for Machined Parts (TI&E).

(2) Determine format to use. In this case, Format CED-TI&E-MP-A-3 (Figure 4.7.5-3) is required.

(3) Study format to determine parameters and conditions necessary for use of the format. For CED-TI&E-MP-A-3 (Figure 4.7.5-3), the volume (in.$^3$) is required. The dimensions of the part are 27" x 11" x 3" = 891 in.$^3$.

(4) From CED-TI&E-MP-A-3, read values for the recurring cost and nonrecurring tooling cost (NRTC):

- Recurring cost at unit 200 = 0.72 man-hours per part
- NRTC = 6.2 man-hours for 200 parts, or 6.2/200 = 0.03 man-hours per part
- Learning curve factor to convert unit cost at 200 to cumulative average cost for a 90% curve and a quantity of 200 is 1.17, from Table 4.7.5-1.

The base part TI&E cost is thus: 1.17 (0.72) + 0.03 = 0.87 man-hours per part.

(5) Check for applicable Designer-Influenced Cost Elements (DICE). The drawing shows that the part has the following type and number of DICE:

DICE

Pockets

Holes

Joggles

Steps

Open/Closed Flange

Format DICE-TI&E-MP-1 (Figure 4.7.5-4) shows the following values for the DICE costs:

- 7 pockets = 0.285
- 4 holes = 0.170
- 1 joggle = 0.024
- 6 steps = 0.135
- 1 Open/closed flange = 0.020.

Adding the DICE costs to the base part recurring cost and nonrecurring tooling costs provides the discrete part TI&E cost.

1.17 (0.72 + 0.285 + 0.170 + 0.024 + 0.135 + 0.020) + 0.03 = <u>1.614 man-hours per part</u>.

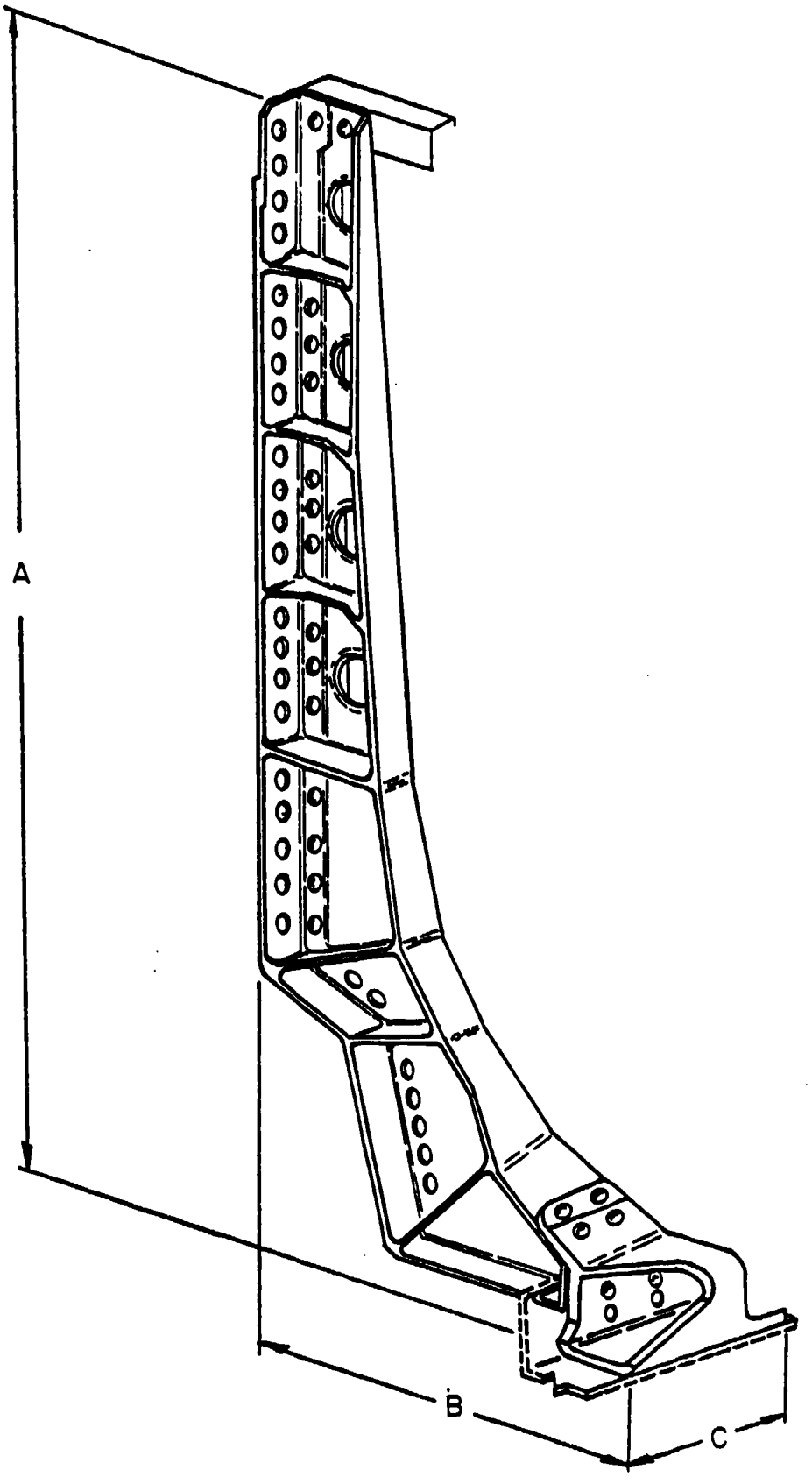



FIGURE 4.7.5-2. ALUMINUM FRAME ANALYZED

# TEST, INSPECTION AND EVALUATION (TI&E)

## ALUMINUM FRAME

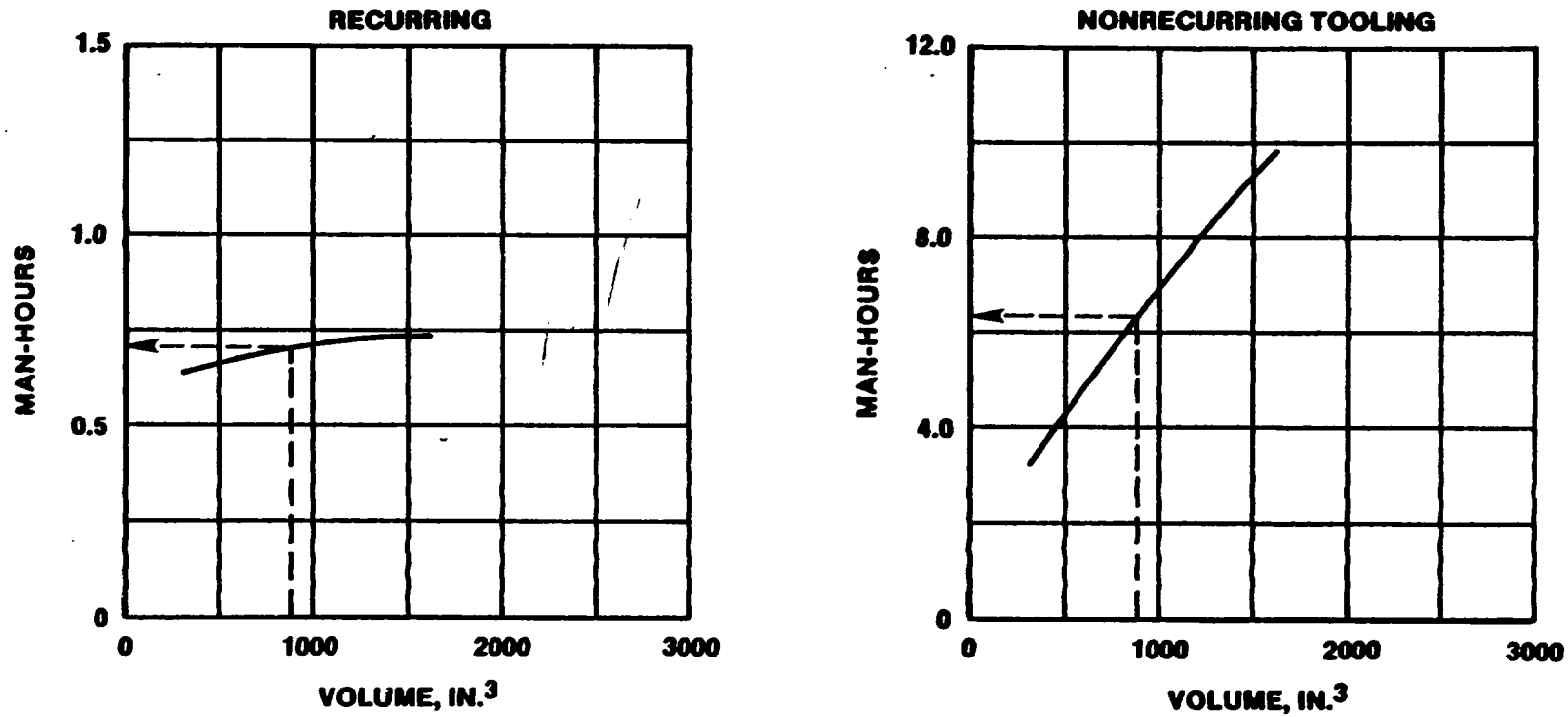



FIGURE 4.7.5-3. FORMAT USED IN EXAMPLE

CED-TI&E-MP-A-3

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED PARTS COST OF TI&E DICE ELEMENTS

## MATERIALS: ALUMINUM, STEEL, TITANIUM

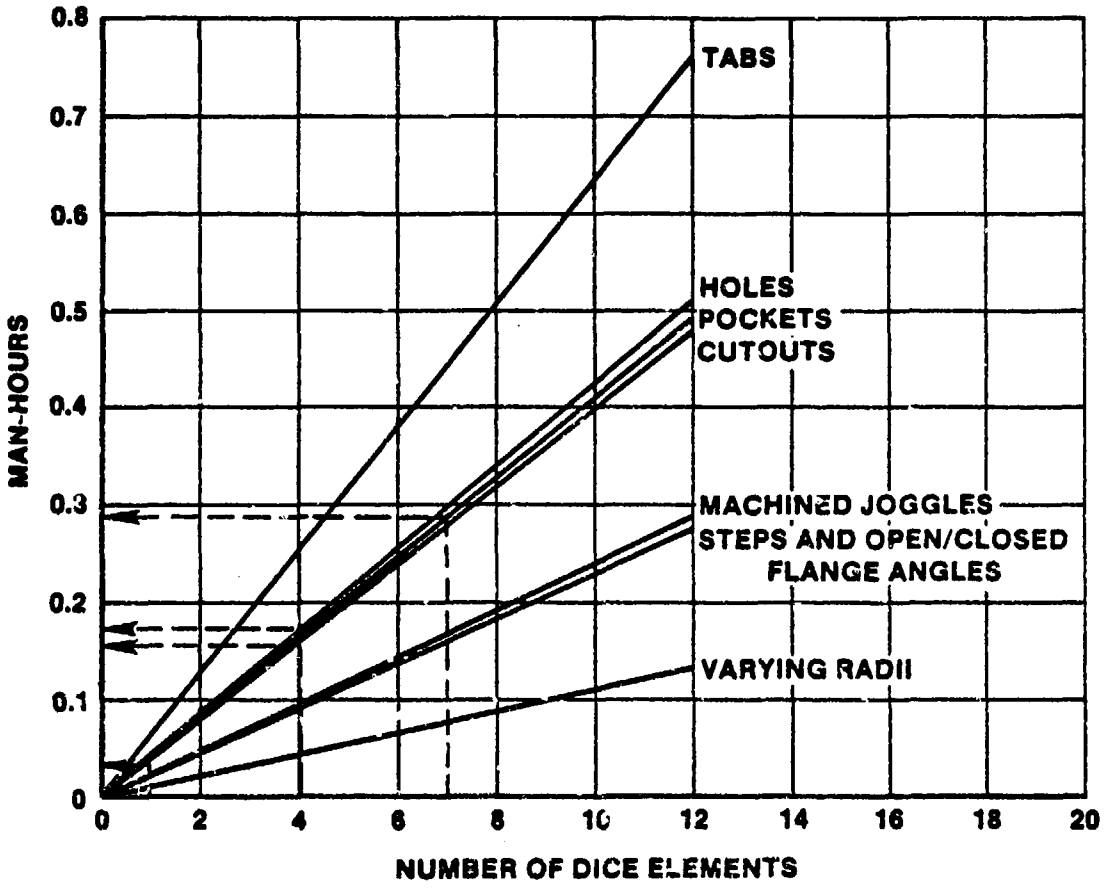



FIGURE 4.7.5-4. FORMAT USED IN EXAMPLE

DICE-TI&E-MP-1

TABLE 4.7.5-1

## FACTORS TO CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED

| DESIGN QUANTITY | LEARNING CURVE-% | | | | | | |
|---|---|---|---|---|---|---|---|
| | 95 | 90 | 85 | 80 | 75 | 70 | 65 |
| 1 | 1.48 | 2.25 | 3.48 | 5.50 | 9.00 | 15.00 | 27.00 |
| 10 | 1.33 | 1.79 | 2.47 | 3.48 | 5.04 | 7.53 | 11.67 |
| 25 | 1.25 | 1.59 | 2.05 | 2.71 | 3.68 | 5.13 | 7.43 |
| 50 | 1.19 | 1.44 | 1.79 | 2.22 | 2.85 | 3.76 | 5.14 |
| 100 | 1.13 | 1.30 | 1.52 | 1.80 | 2.18 | 2.73 | 3.51 |
| 200 | 1.08 | 1.17 | 1.30 | 1.45 | 1.66 | 1.95 | 2.36 |
| 350 | 1.04 | 1.08 | 1.14 | 1.22 | 1.33 | 1.48 | 1.70 |
| 500 | 1.01 | 1.02 | 1.05 | 1.09 | 1.15 | 1.24 | 1.38 |
| 750 | 0.98 | 0.96 | 0.96 | 0.96 | 0.97 | 1.01 | 1.09 |
| 1000 | 0.96 | 0.92 | 0.89 | 0.87 | 0.87 | 0.88 | 0.91 |

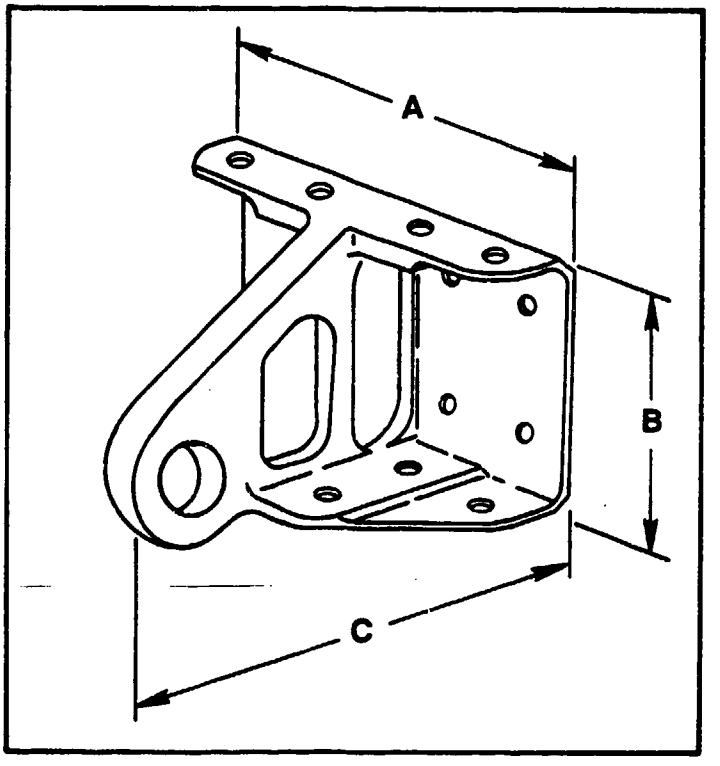
4.7.5.3 Airframe Parts Analyzed

The airframe parts studied to determine the TI&E costs for machining are shown in Figures 4.7.5-5 to 4.7.5-9. The parts are representative of brackets, longerons, spar caps, bulkhead, and frame.

# BEARING BRACKET (BASE PART)

**MC/DG-M*-1**

*** = A (ALUMINUM)**
**S (STEEL)**




**BASE PART CHARACTERISTICS**

- **CONSTANT WEB & FLANGE THICKNESS**
- **ALL SURFACE PLANES ARE PERPENDICULAR TO EACH OTHER**

FIGURE 4.7.5-5

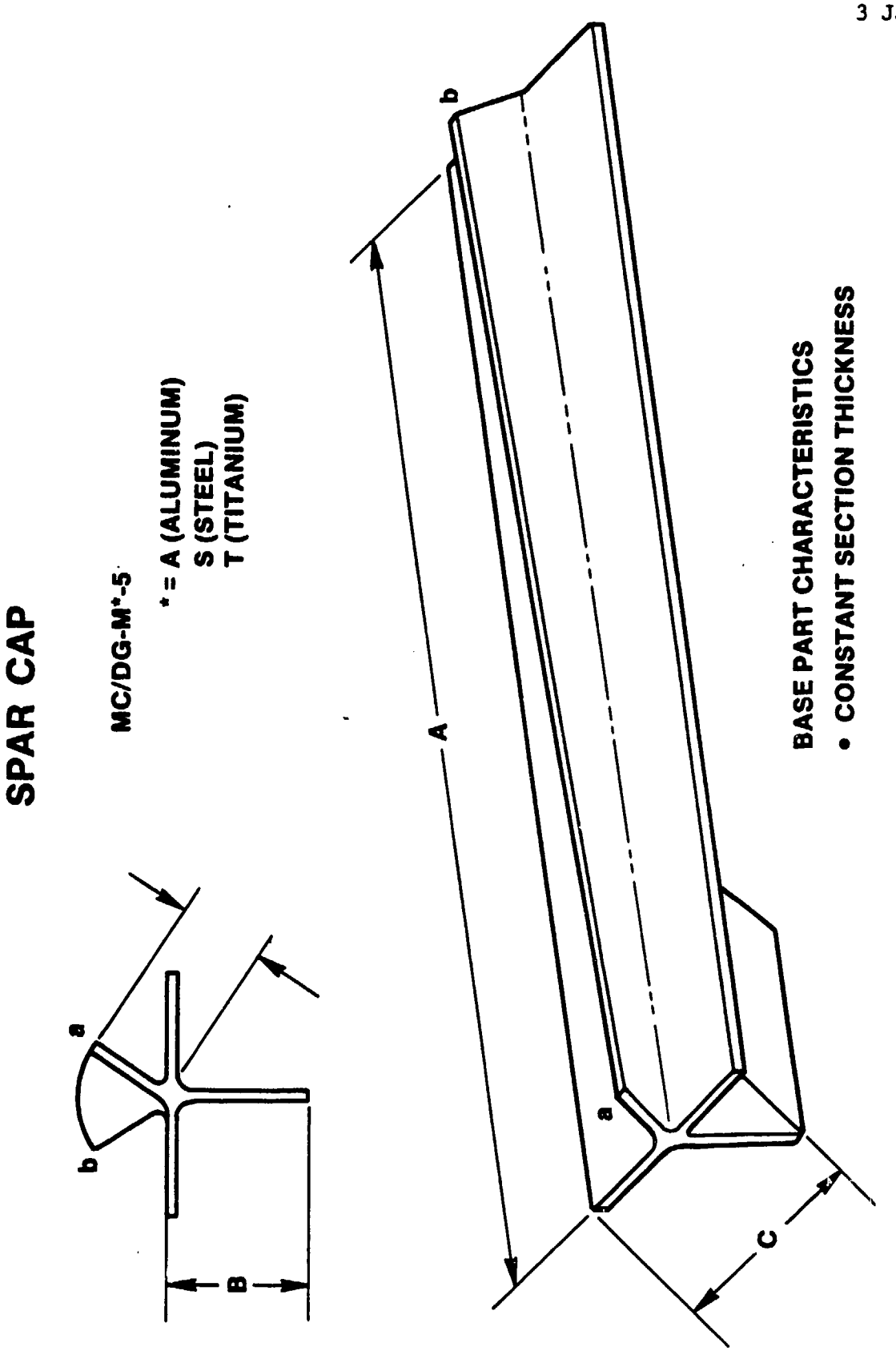

SPAR CAP
MC/DG-M*-5
* = A (ALUMINUM)
S (STEEL)
T (TITANIUM)
a
b
B
A
C
BASE PART CHARACTERISTICS
• CONSTANT SECTION THICKNESS

FIGURE 4.7.5-6

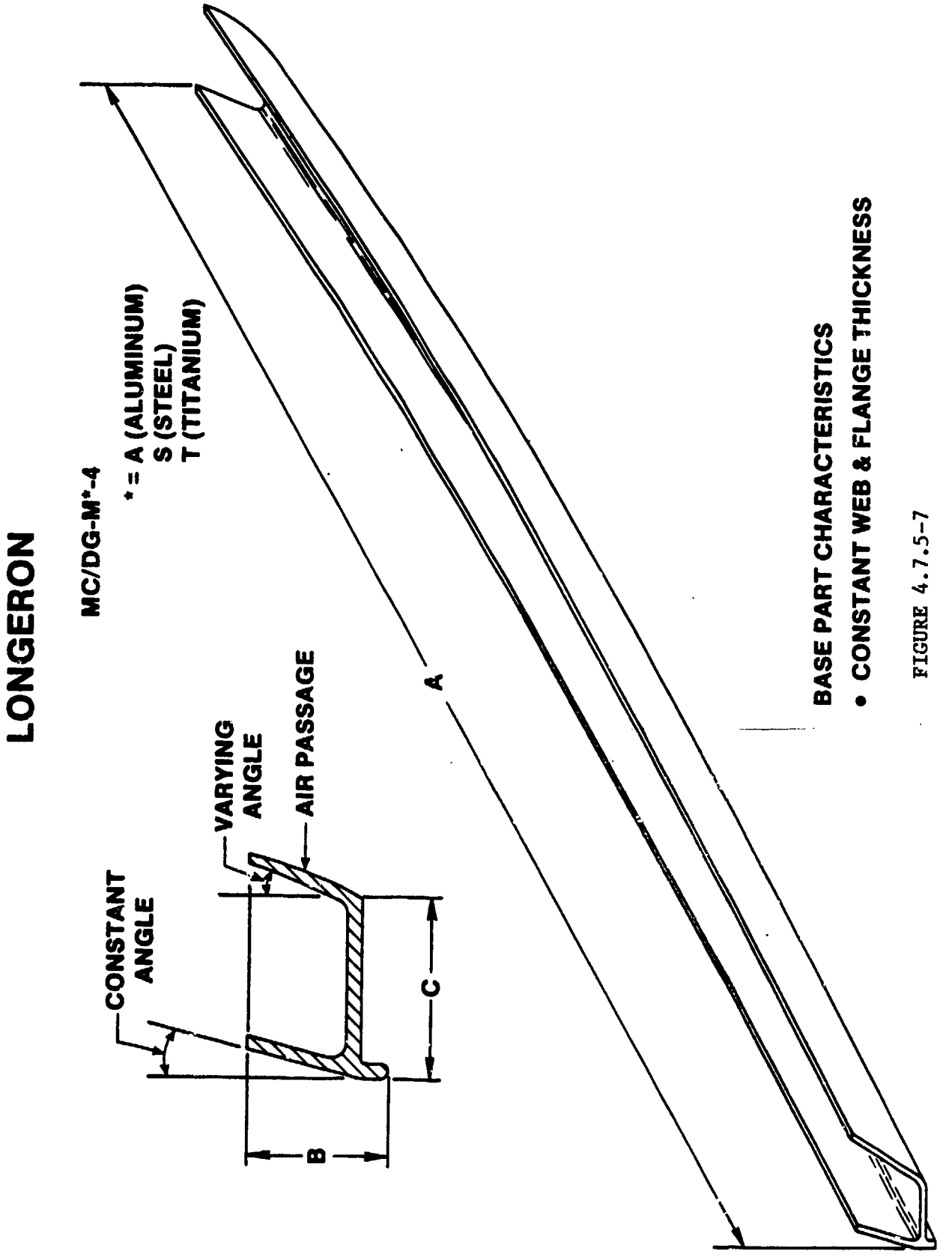
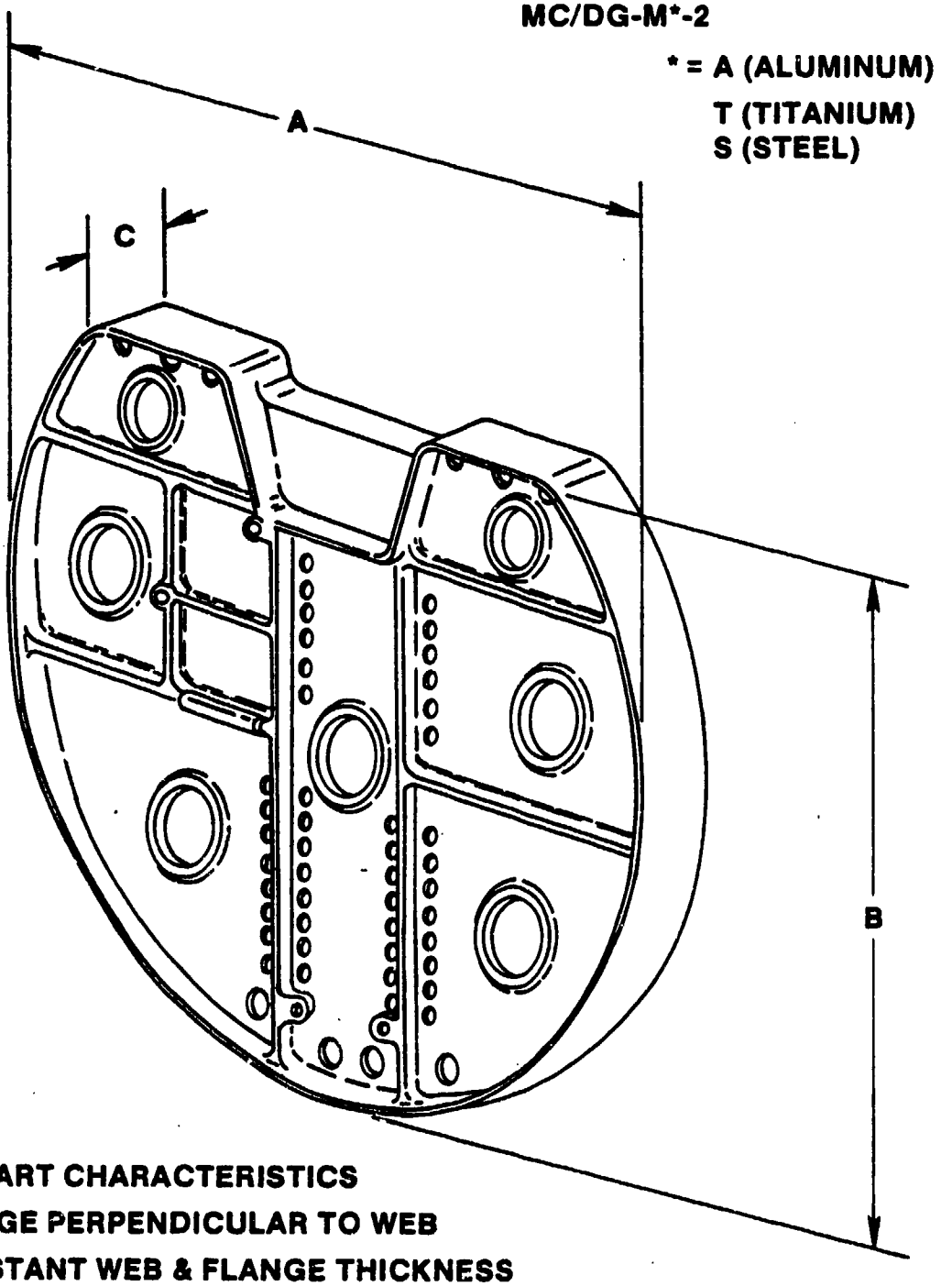

LONGERON
MC/DG-M*-4
* = A (ALUMINUM)
S (STEEL)
T (TITANIUM)
CONSTANT ANGLE
VARYING ANGLE
AIR PASSAGE
A
B
C
BASE PART CHARACTERISTICS
• CONSTANT WEB & FLANGE THICKNESS

FIGURE 4.7.5-7

# BULKHEAD

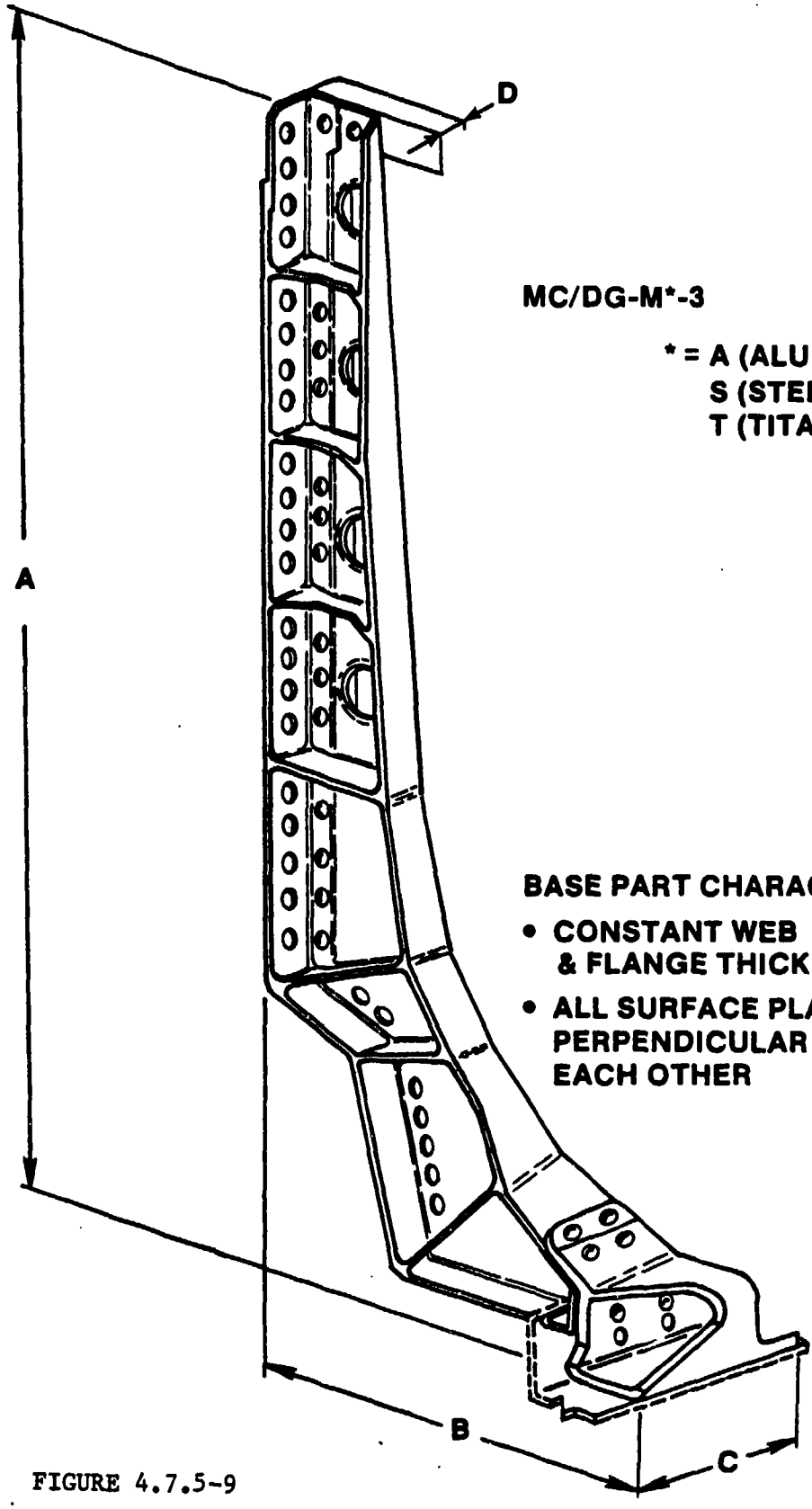



**BASE PART CHARACTERISTICS**

- **FLANGE PERPENDICULAR TO WEB**
- **CONSTANT WEB & FLANGE THICKNESS**

FIGURE 4.7.5-8

# FRAME—BASE PART




MC/DG-M*-3

* = A (ALUMINUM)
S (STEEL)
T (TITANIUM)

**BASE PART CHARACTERISTICS**

- CONSTANT WEB & FLANGE THICKNESS
- ALL SURFACE PLANES ARE PERPENDICULAR TO EACH OTHER

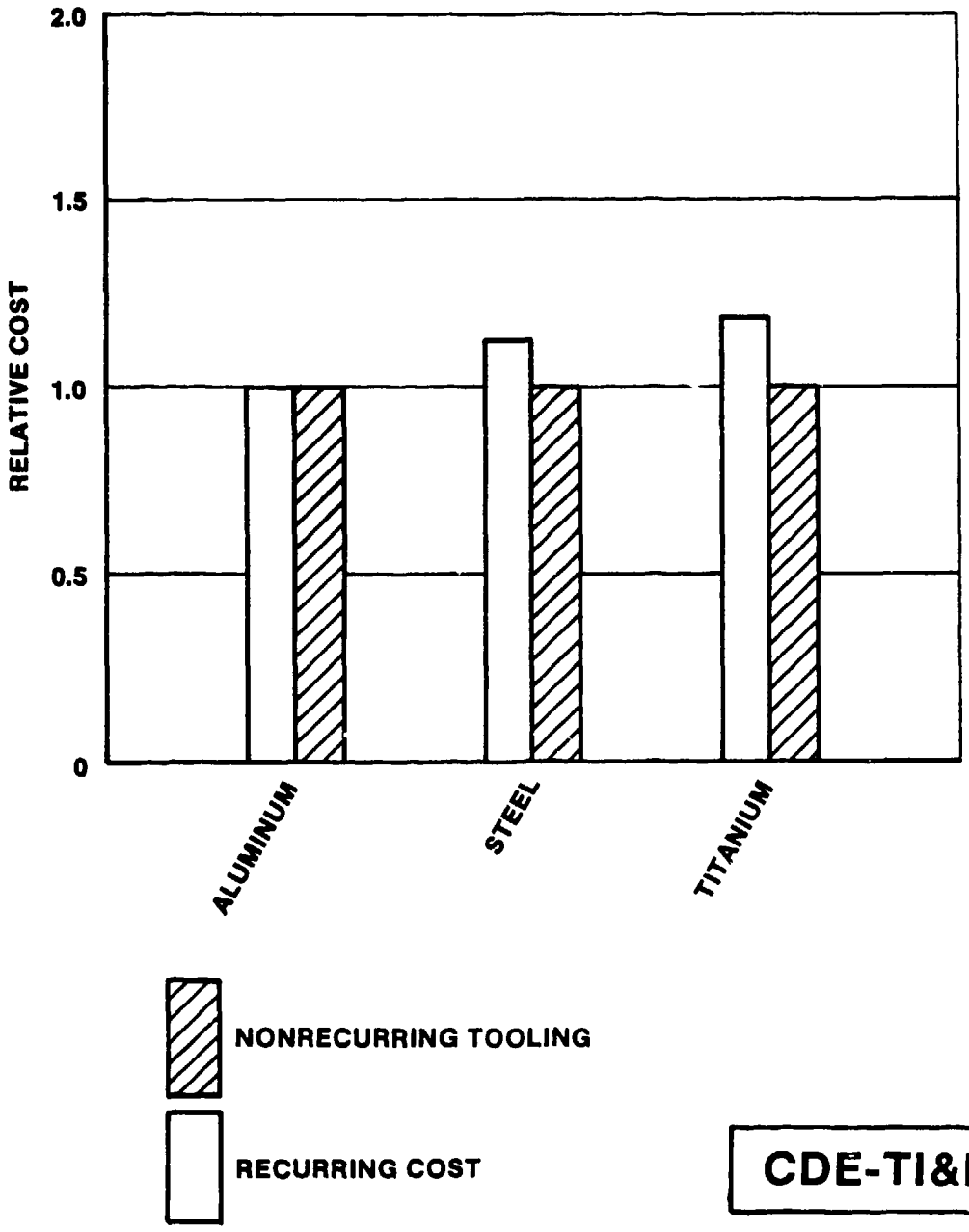
FIGURE 4.7.5-9

4.7.5.4 TI&E Data for Machined Parts

The TI&E data for machining on the following pages are presented to the designer using cost-estimating data (CED), cost-driver effect (CDE) and designer-influenced cost elements (DICE) formats.

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED PARTS COST DRIVER EFFECT

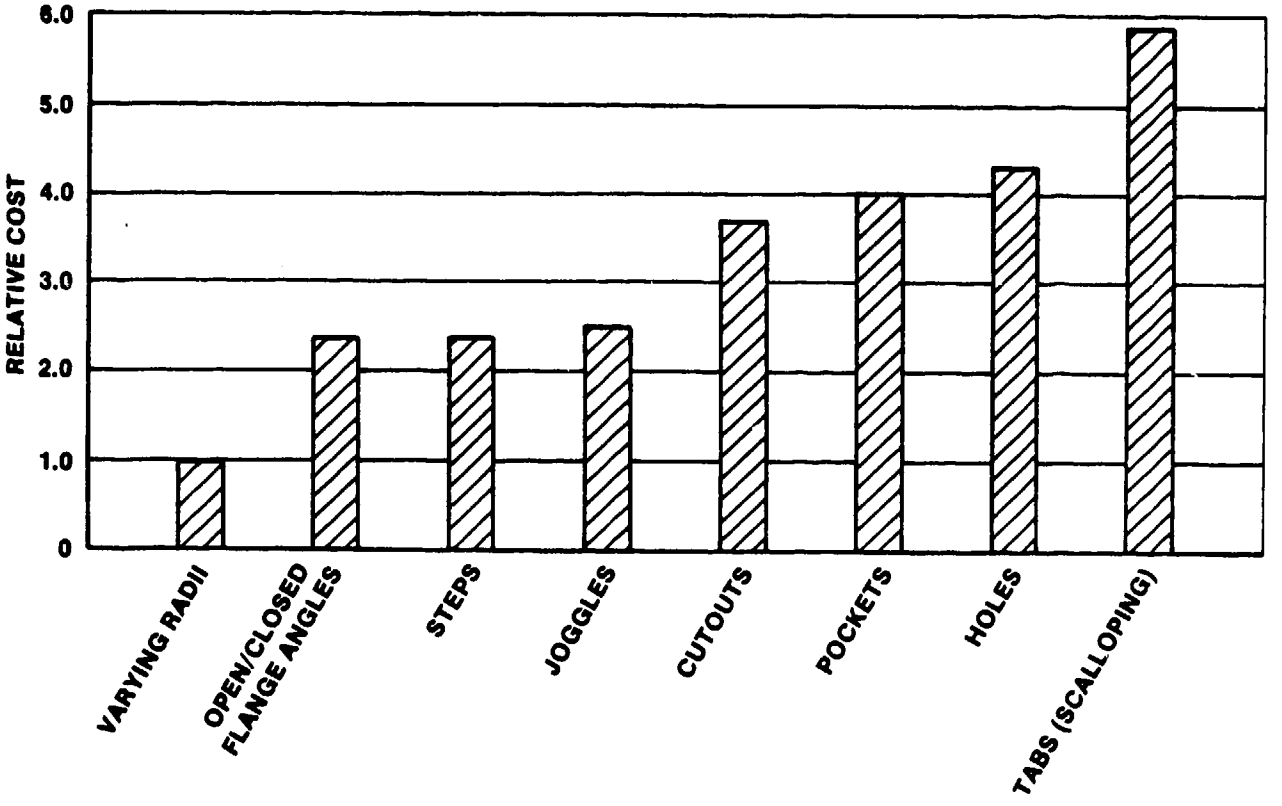
## EFFECT OF MATERIAL ON TI&E COSTS




CDE-TI&E-MP-I

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED PARTS COST DRIVER EFFECT

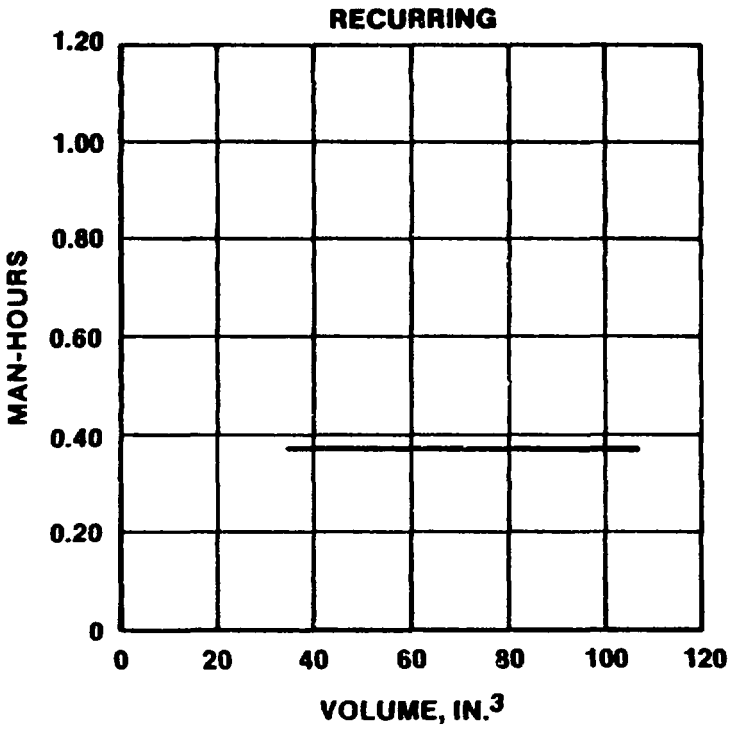
## EFFECT OF DICE

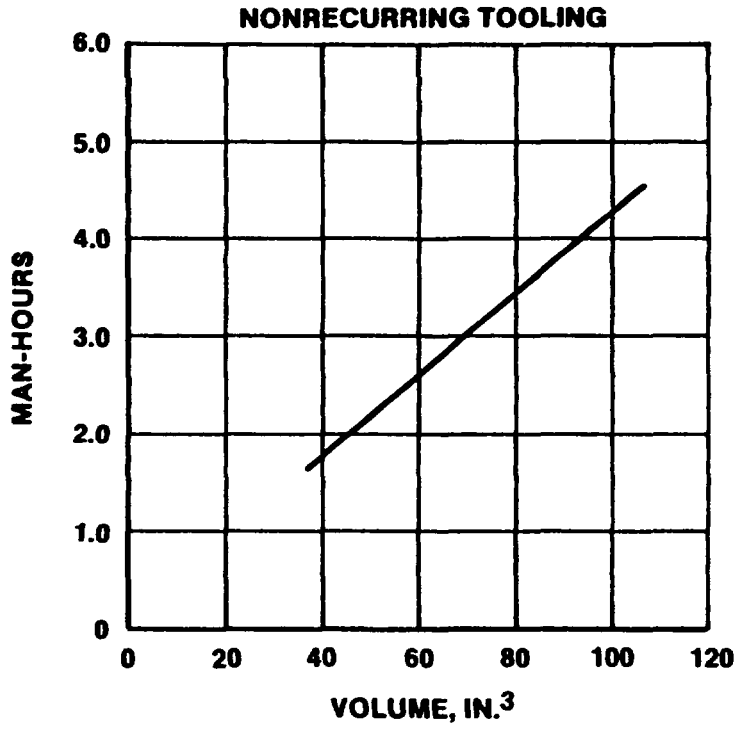



CDE-TI&E-MP-II

# TEST, INSPECTION AND EVALUATION (TI&E)

## ALUMINUM BEARING BRACKET




APPLICABLE DICE
(B, C, D, E, F)

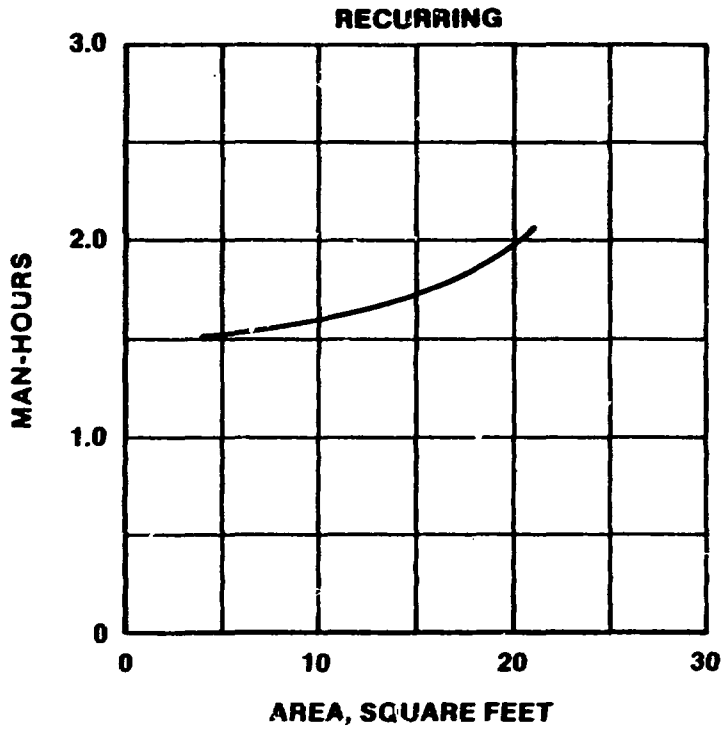
CED-TI&E-MP-A-1

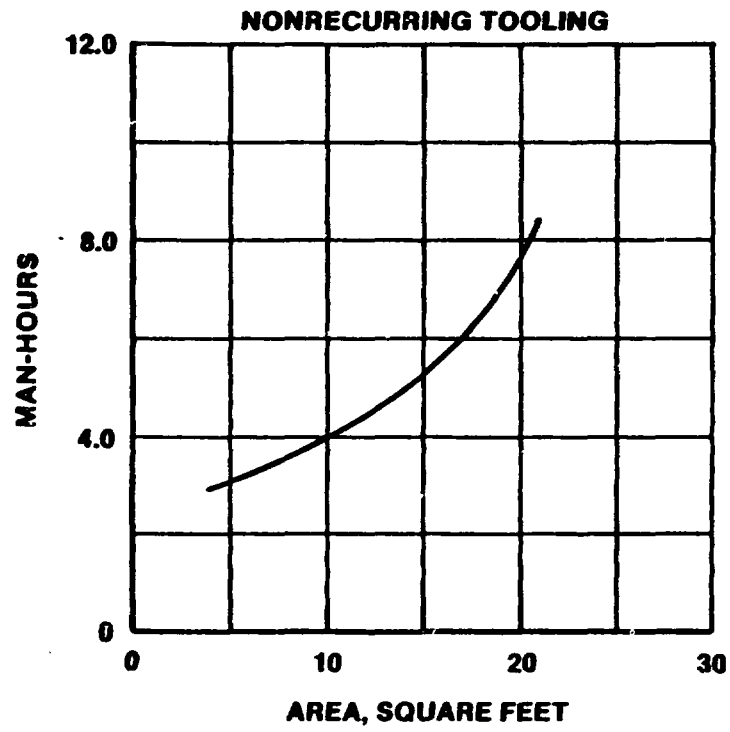


FTR450261000U
3 Jan 1983

# TEST, INSPECTION AND EVALUATION (TI&E)

## ALUMINUM BULKHEAD



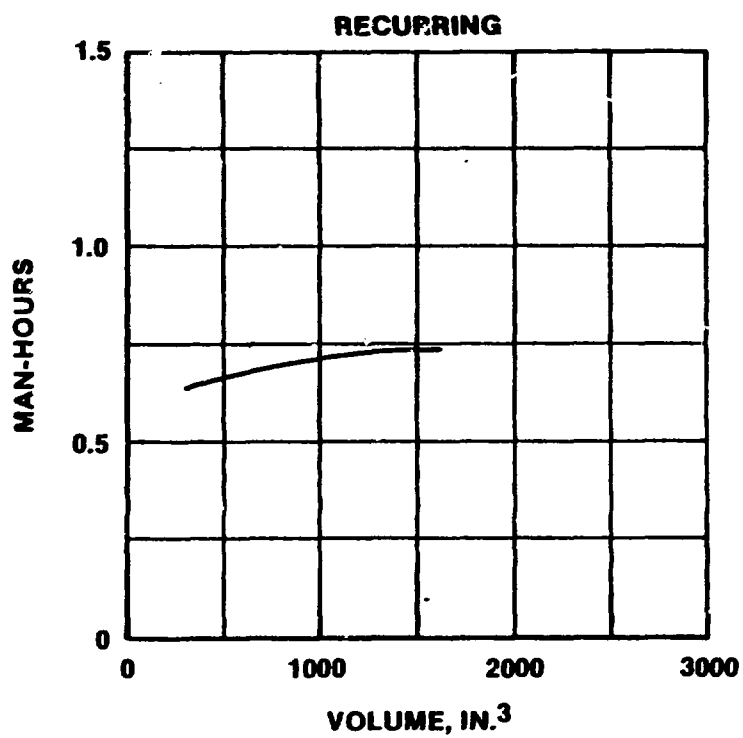

CED-TI&E-MP-A-2

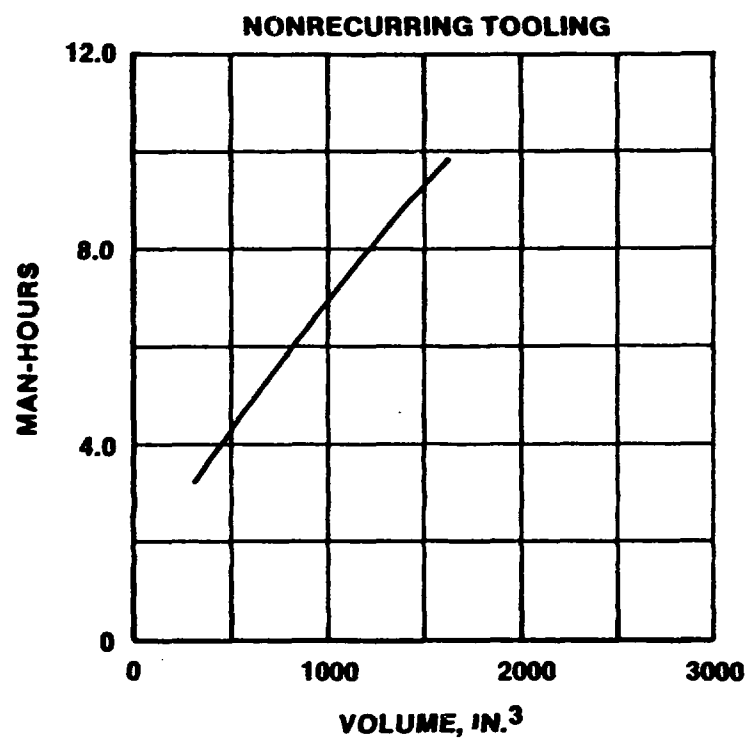


FTR45026100U
3 Jan 1983

# TEST, INSPECTION AND EVALUATION (TI&E)

## ALUMINUM FRAME



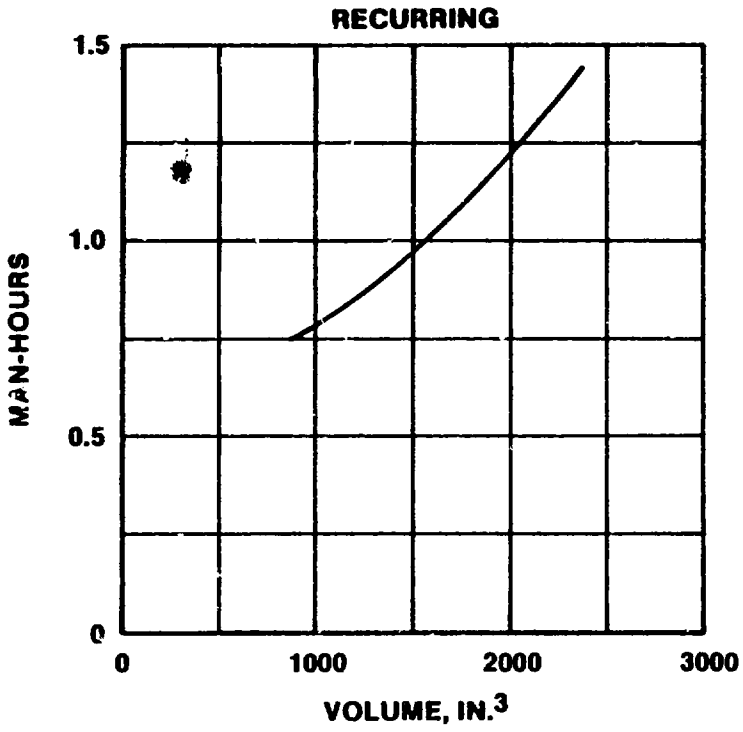

CED-TI&E-MP-A-3

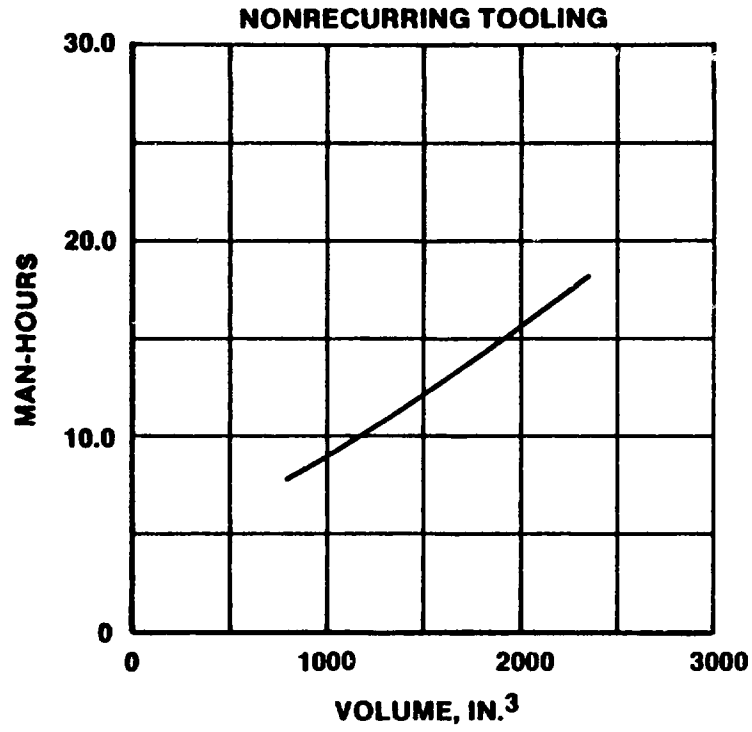


FTR450261000U
3 Jan 1983

# TEST, INSPECTION AND EVALUATION (TI&E)

## ALUMINUM LONGERON

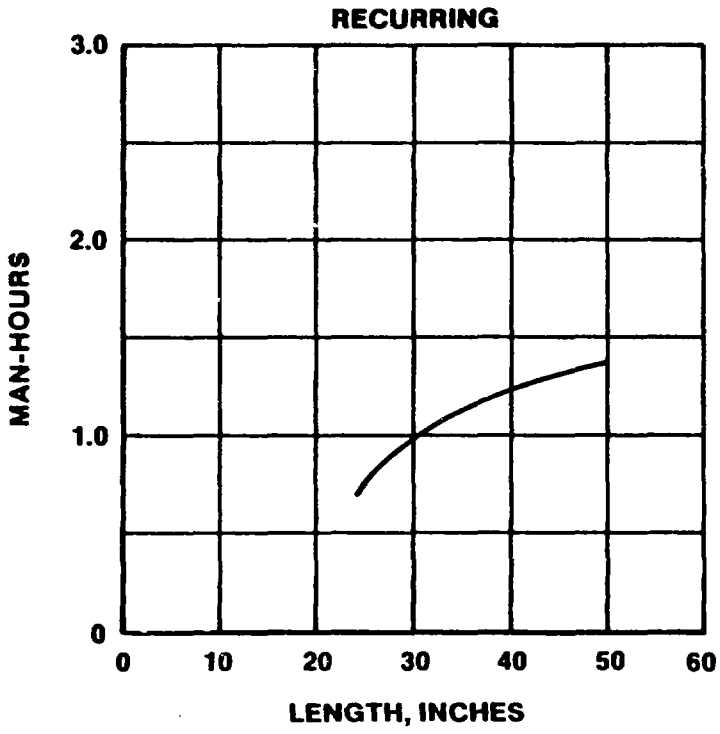


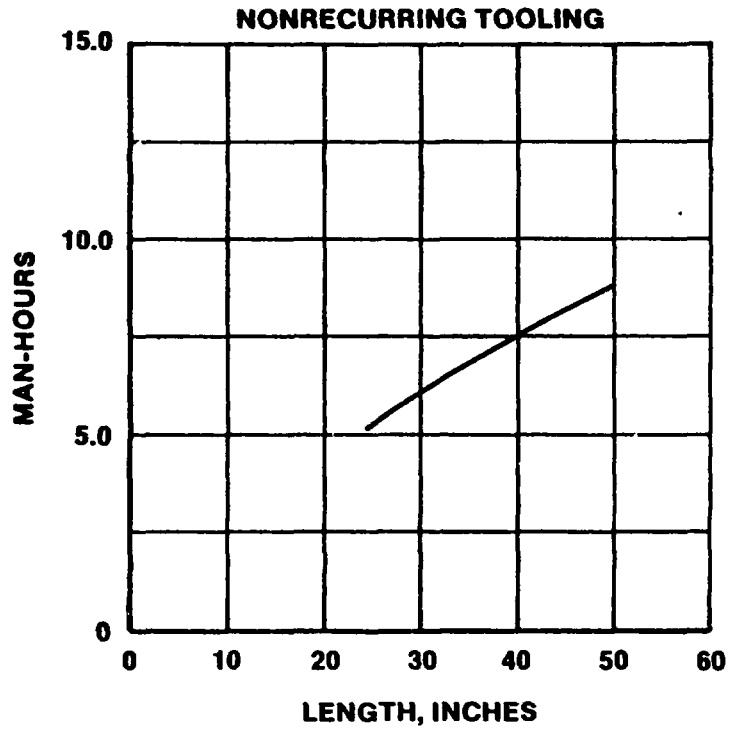




CED-TI&E-MP-A-4

# TEST, INSPECTION AND EVALUATION (TI&E)

## ALUMINUM SPAR CAP



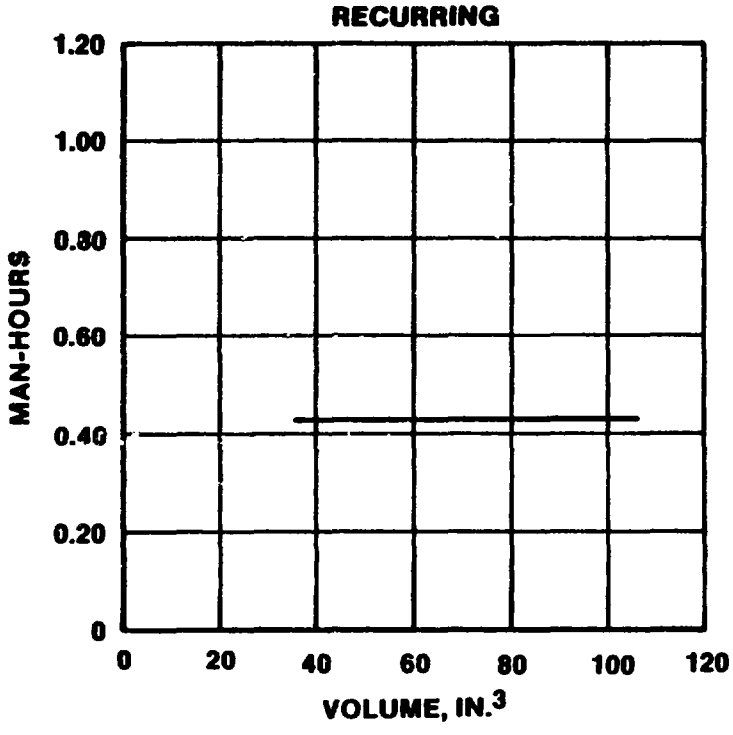



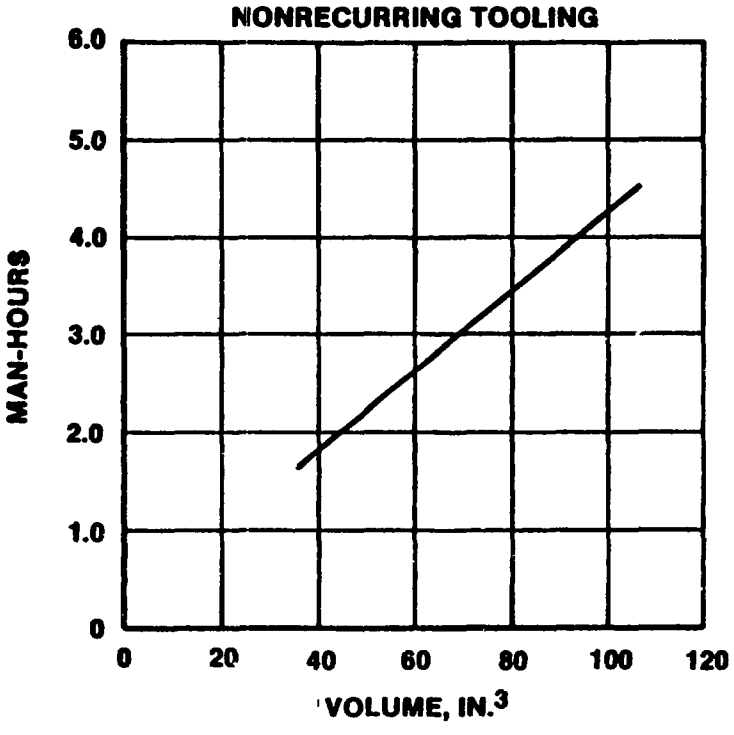

APPLICABLE DICE
(A, B, C, D, E, F, G)

CED-TI&E-MP-A-5

# TEST, INSPECTION AND EVALUATION (TI&E)

## STEEL BEARING BRACKET



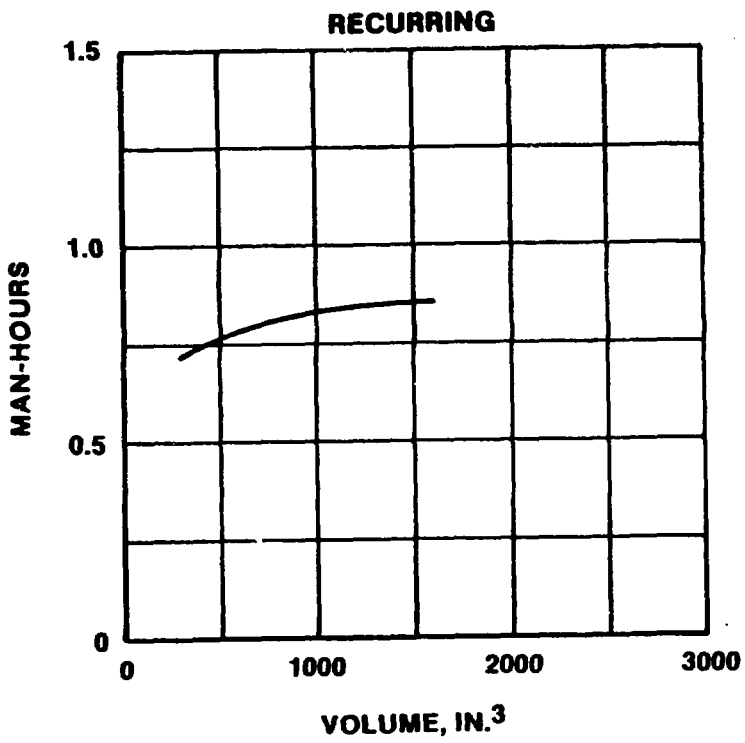



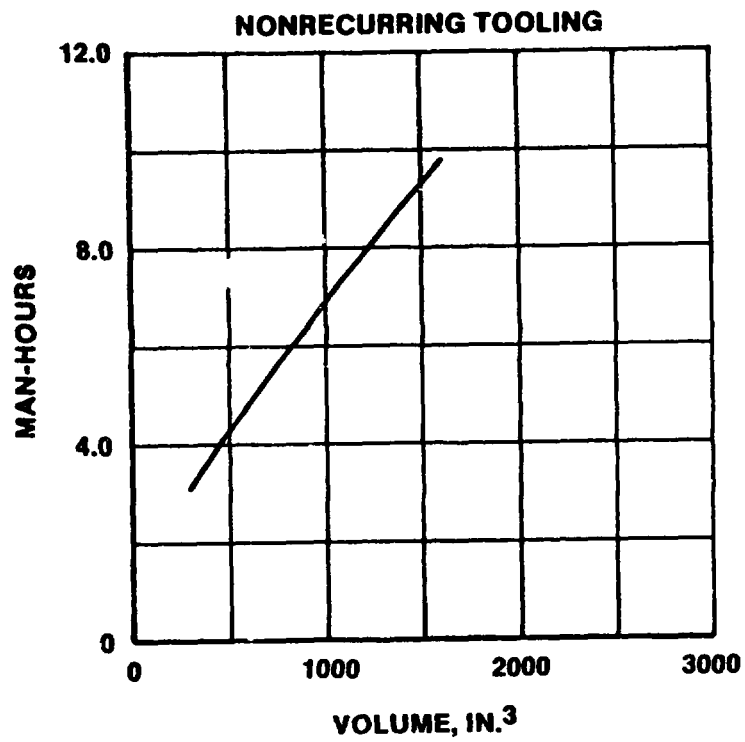

APPLICABLE DICE
(B,C,D,E,F)

CED-TI&E-MP-S-1

# TEST, INSPECTION AND EVALUATION (TI&E)

## STEEL FRAME

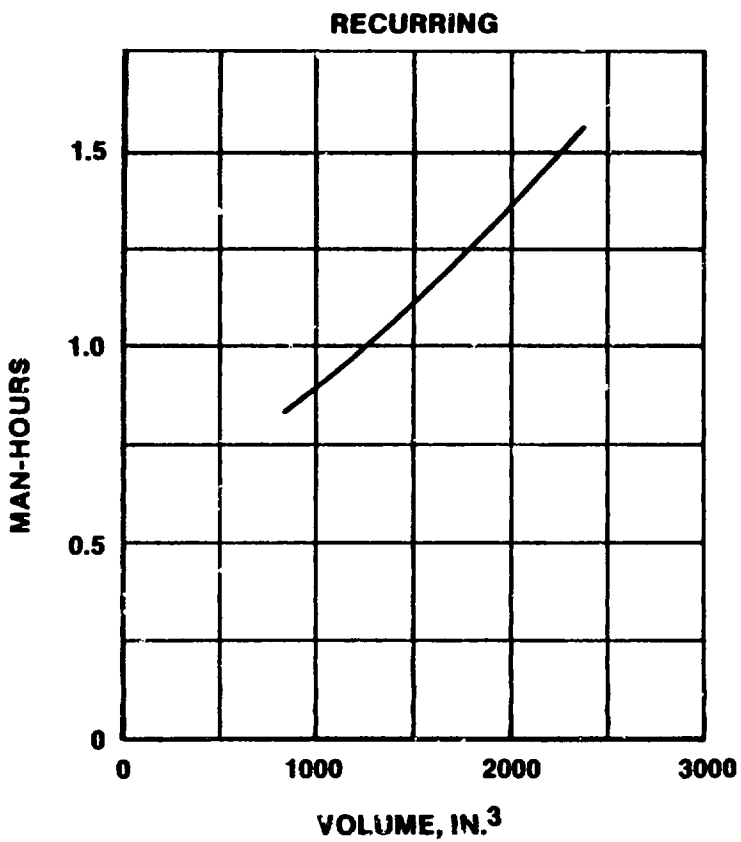


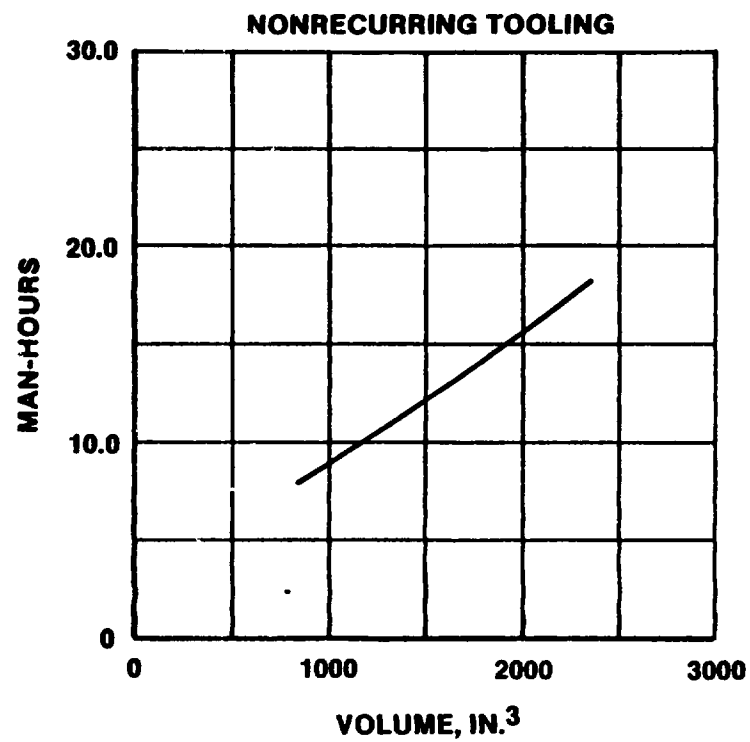




CED-TI&E-MP-S-2

# TEST, INSPECTION AND EVALUATION (TI&E)

## STEEL LONGERON



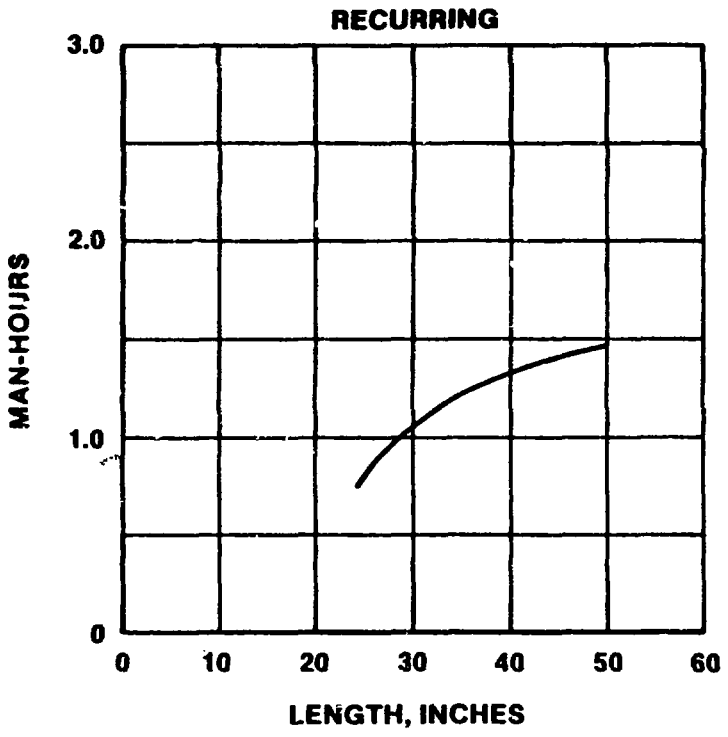

CED-TI&E-MP-S-3

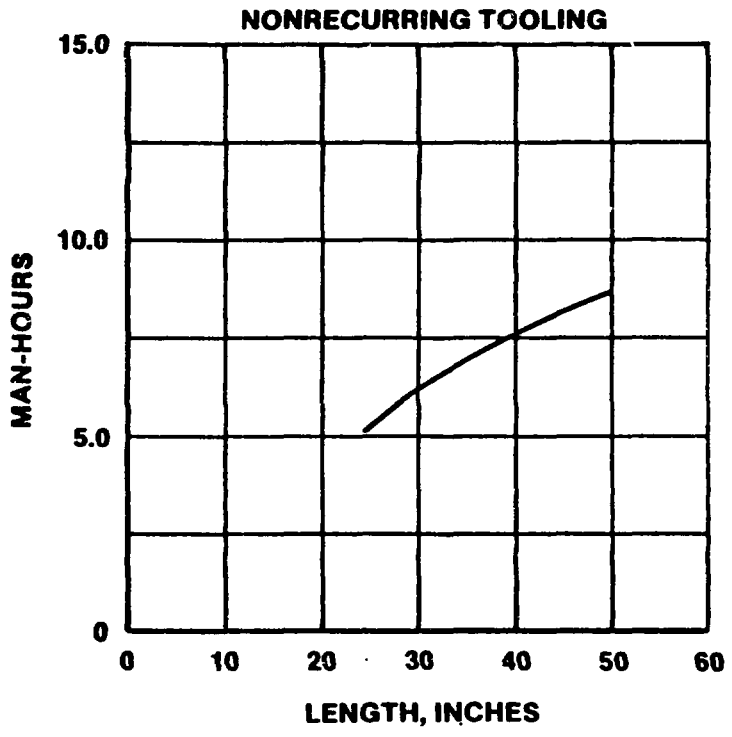


FTR450261000U
3 Jan 1983

# TEST, INSPECTION AND EVALUATION (TI&E)

## STEEL SPAR CAP




APPLICABLE DICE
(A, B, C, D, E, F, G)

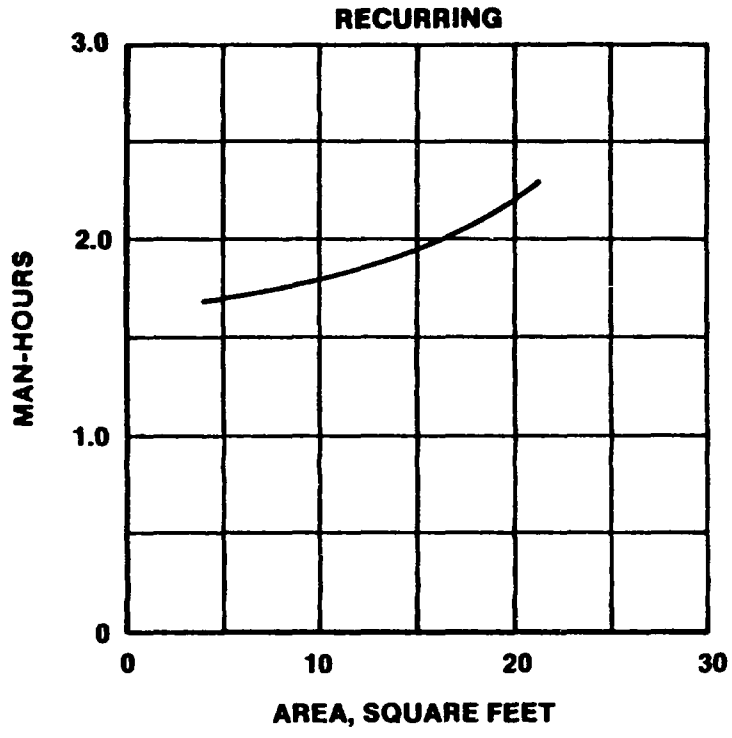
4.7.5-26

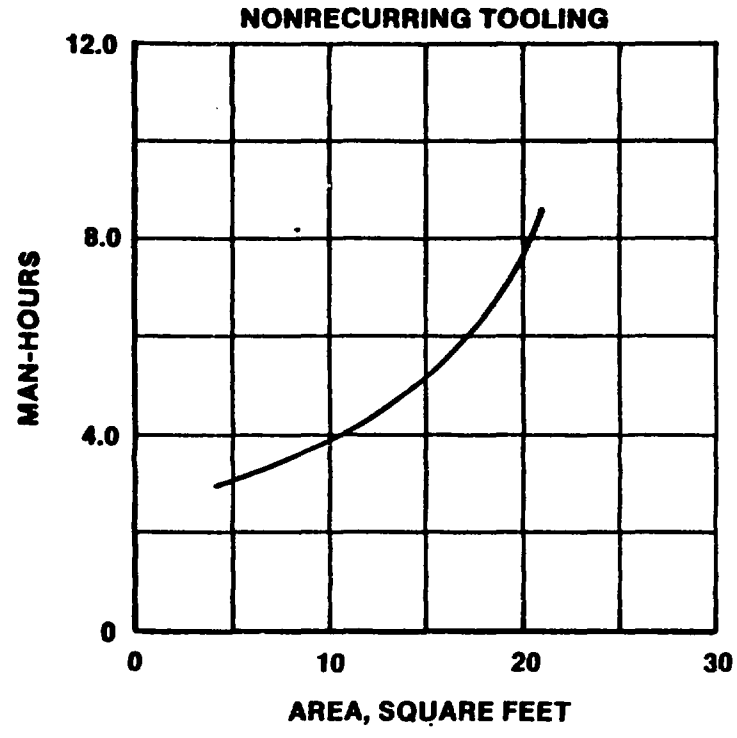
FTR450261000U
3 Jan 1983

CED-TI&E-MP-S-4

# TEST, INSPECTION AND EVALUATION (TI&E)

## TITANIUM BULKHEAD



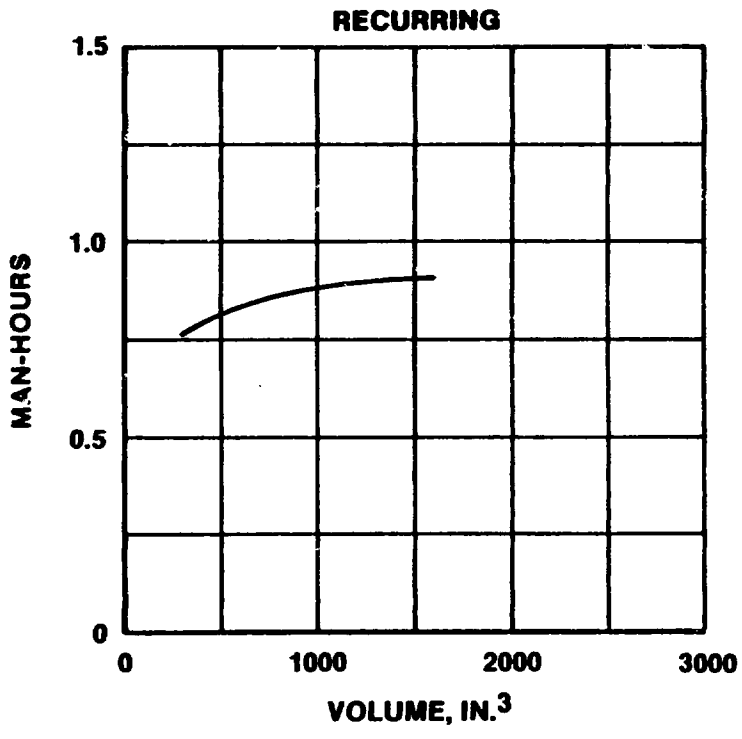

CED-TI&E-MP-T-1

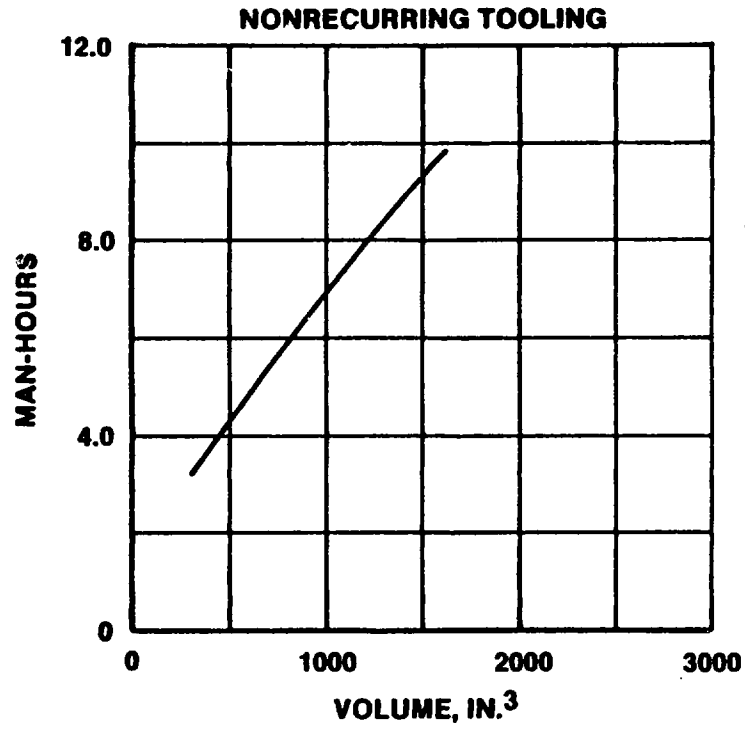


FTR450261000U
3 Jan 1983

# TEST, INSPECTION AND EVALUATION (TI&E)

## TITANIUM FRAME

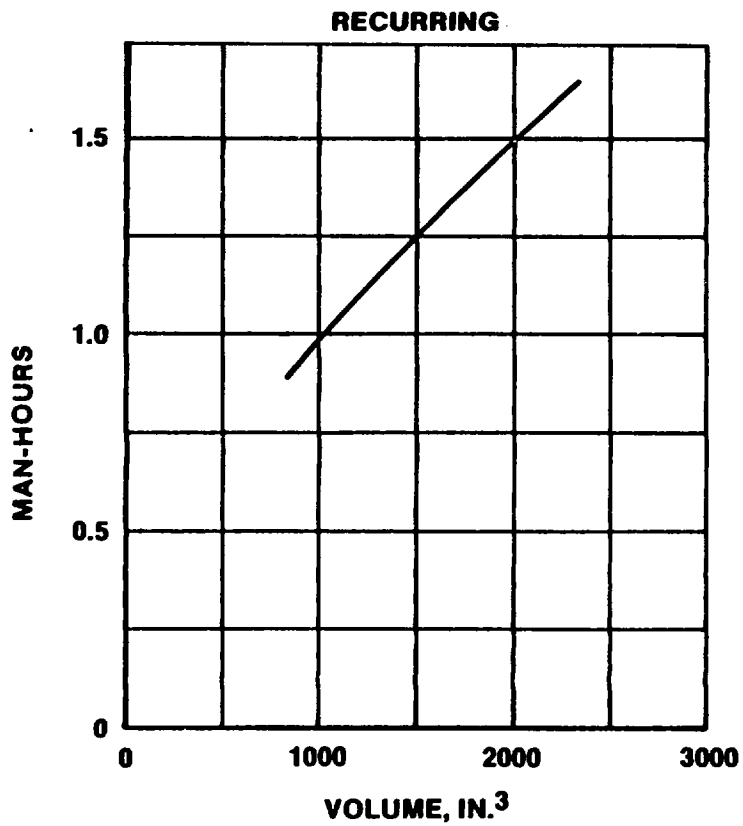


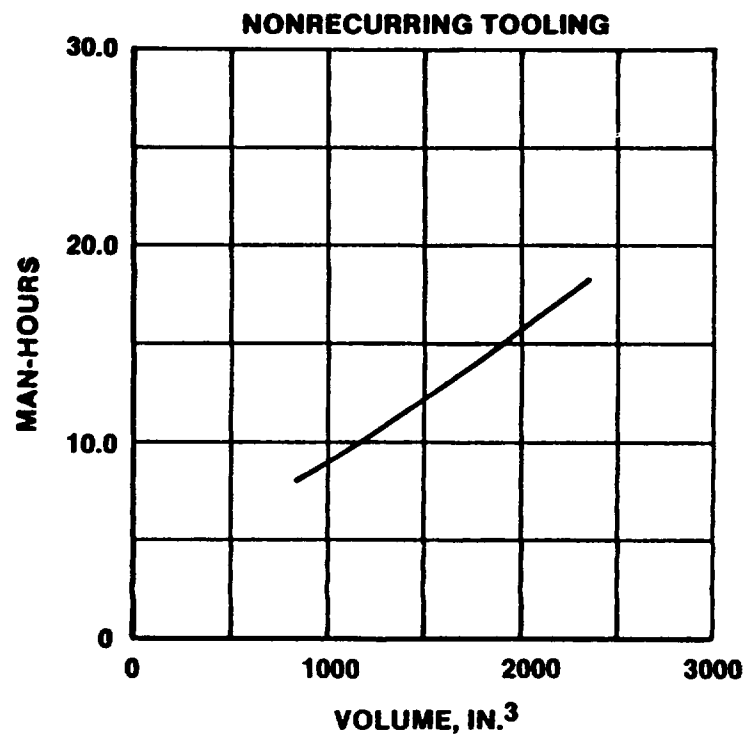




CED-TI&E-MP-T-2

# TEST, INSPECTION AND EVALUATION (TI&E)

## TITANIUM LONGERON



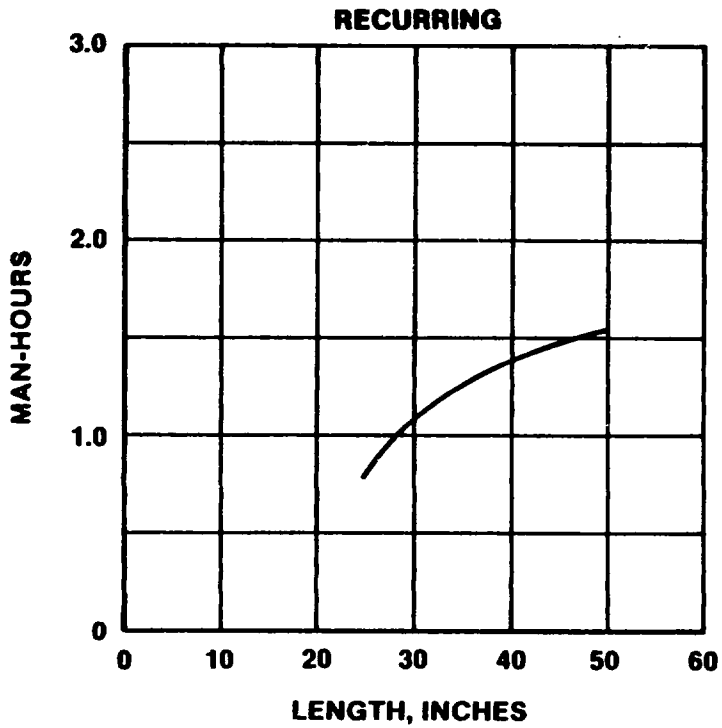

CED-TI&E-MP-T-3

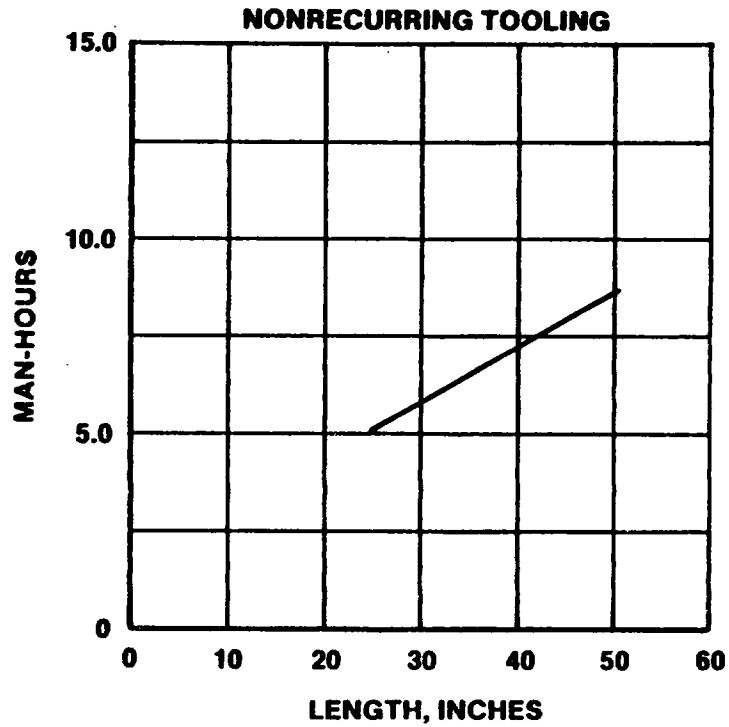


FTR450261000U
3 Jan 1983

# TEST, INSPECTION AND EVALUATION (TI&E)

## TITANIUM SPAR CAP



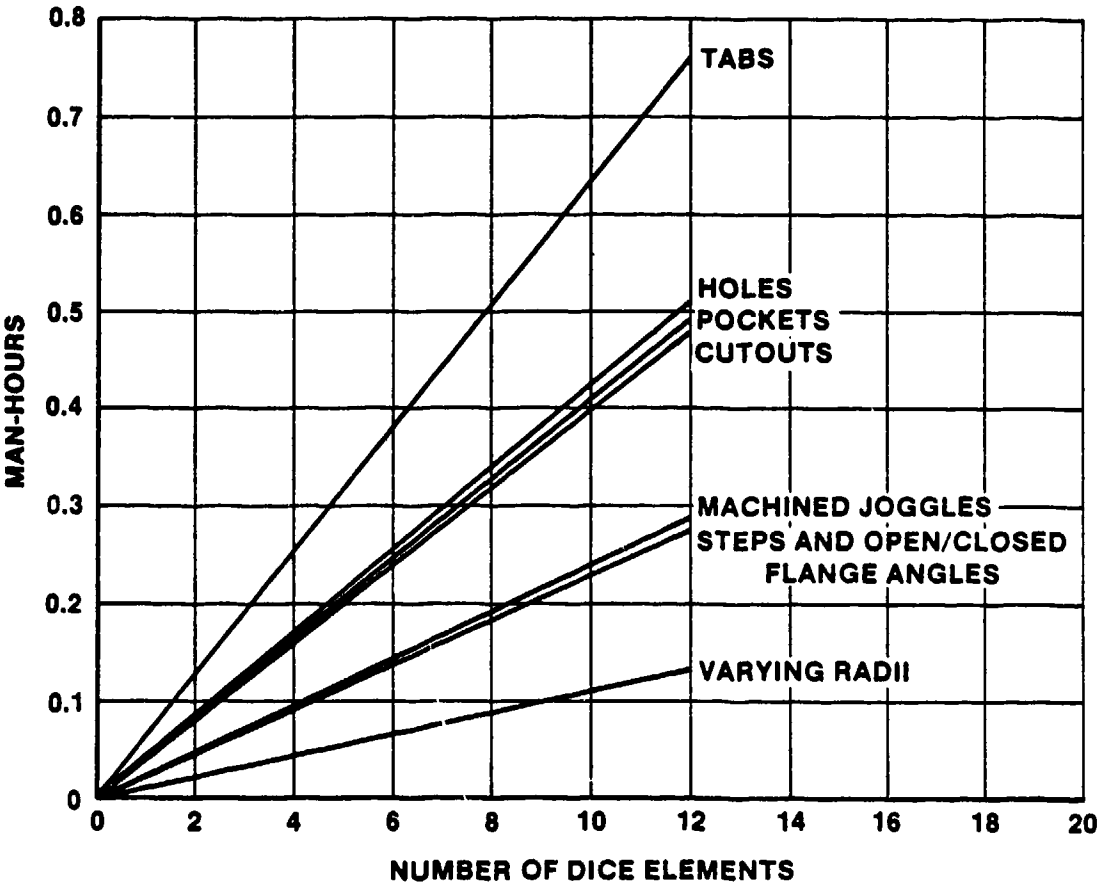




APPLICABLE DICE
(A,B,C,D,E,F,G)

CED-TI&E-MP-T-4

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED PARTS COST OF TI&E DICE ELEMENTS

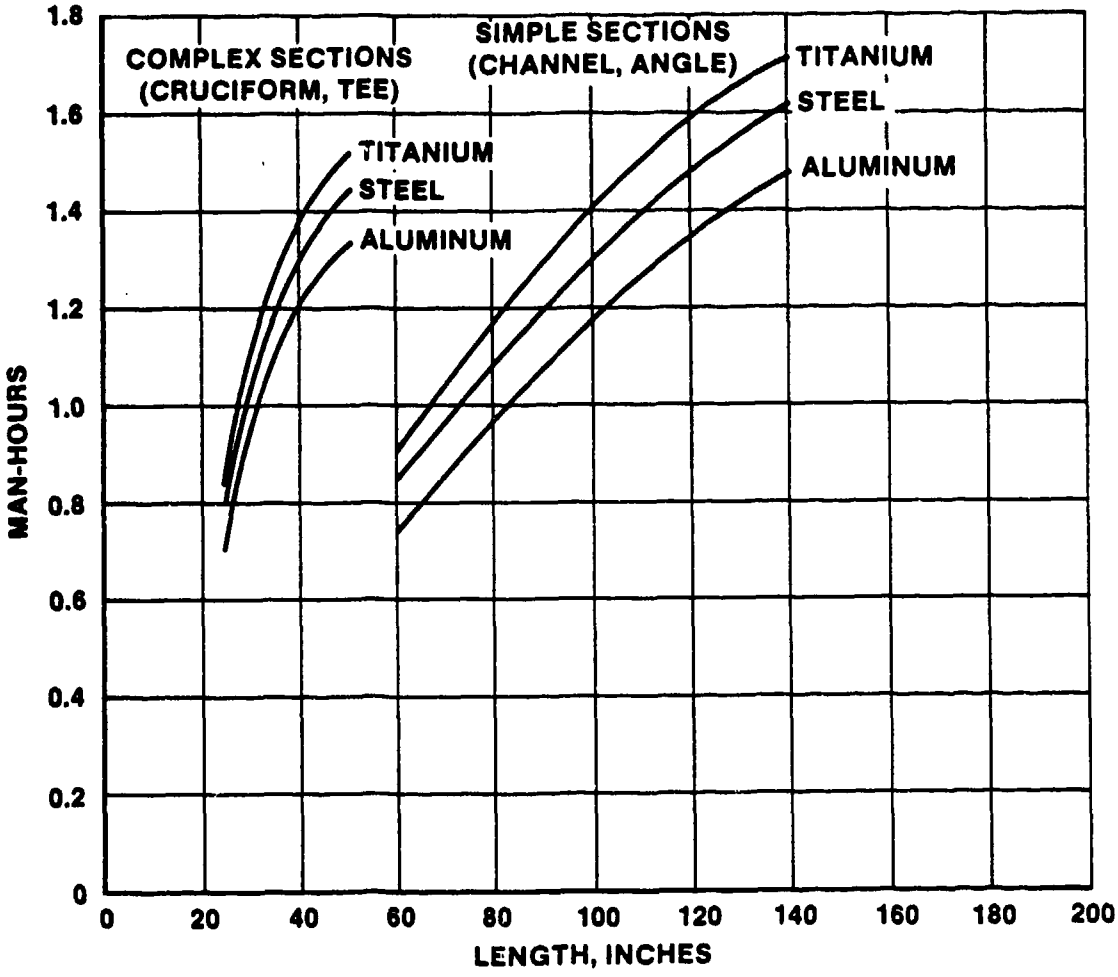
## MATERIALS: ALUMINUM, STEEL, TITANIUM




DICE-TI&E-MP-1

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED LINEAL PARTS

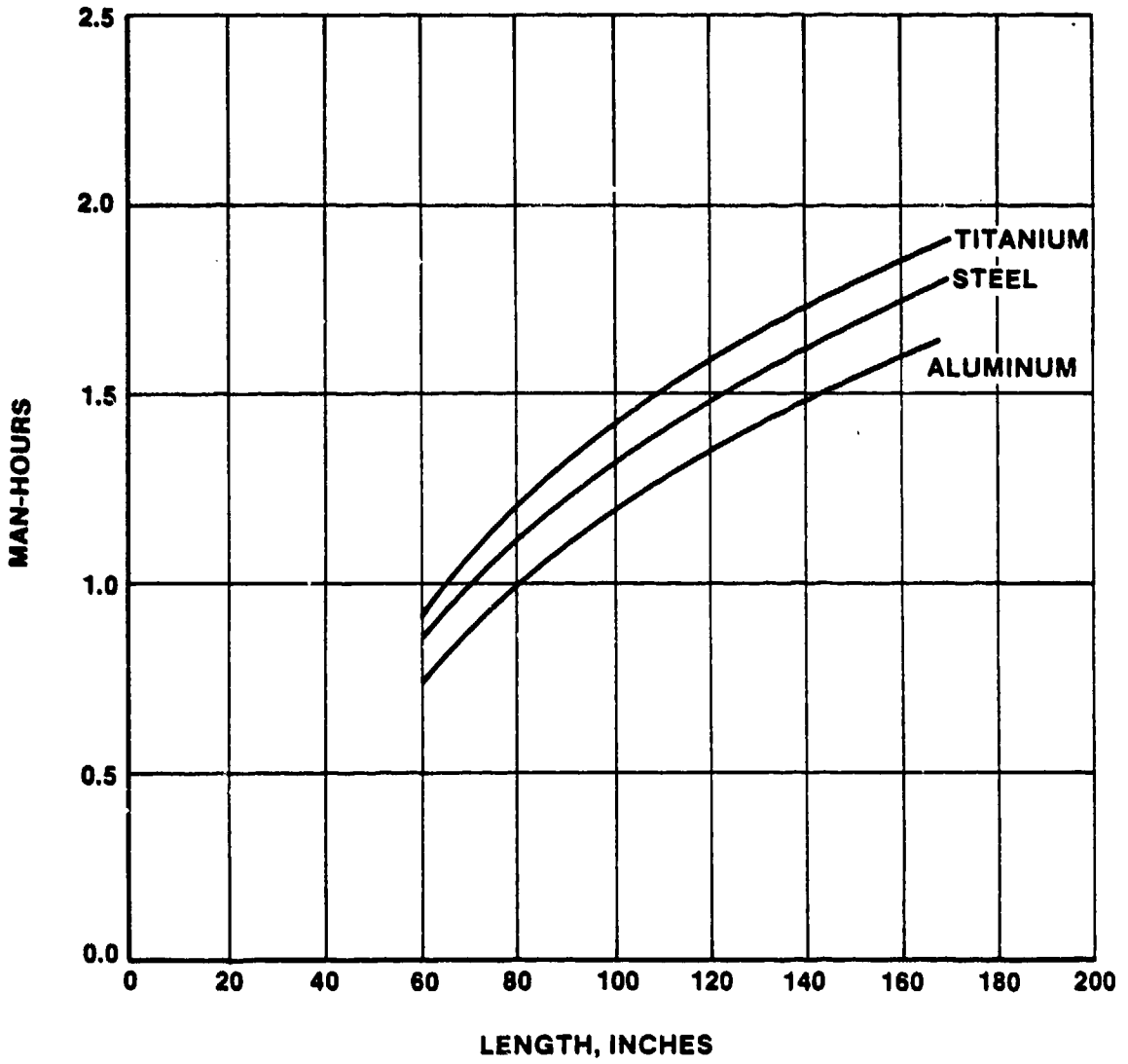
## BASE PART RECURRING TI&E COST




CED-TI&E-MP-M-1

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED LINEAL PARTS SIMPLE SECTIONS

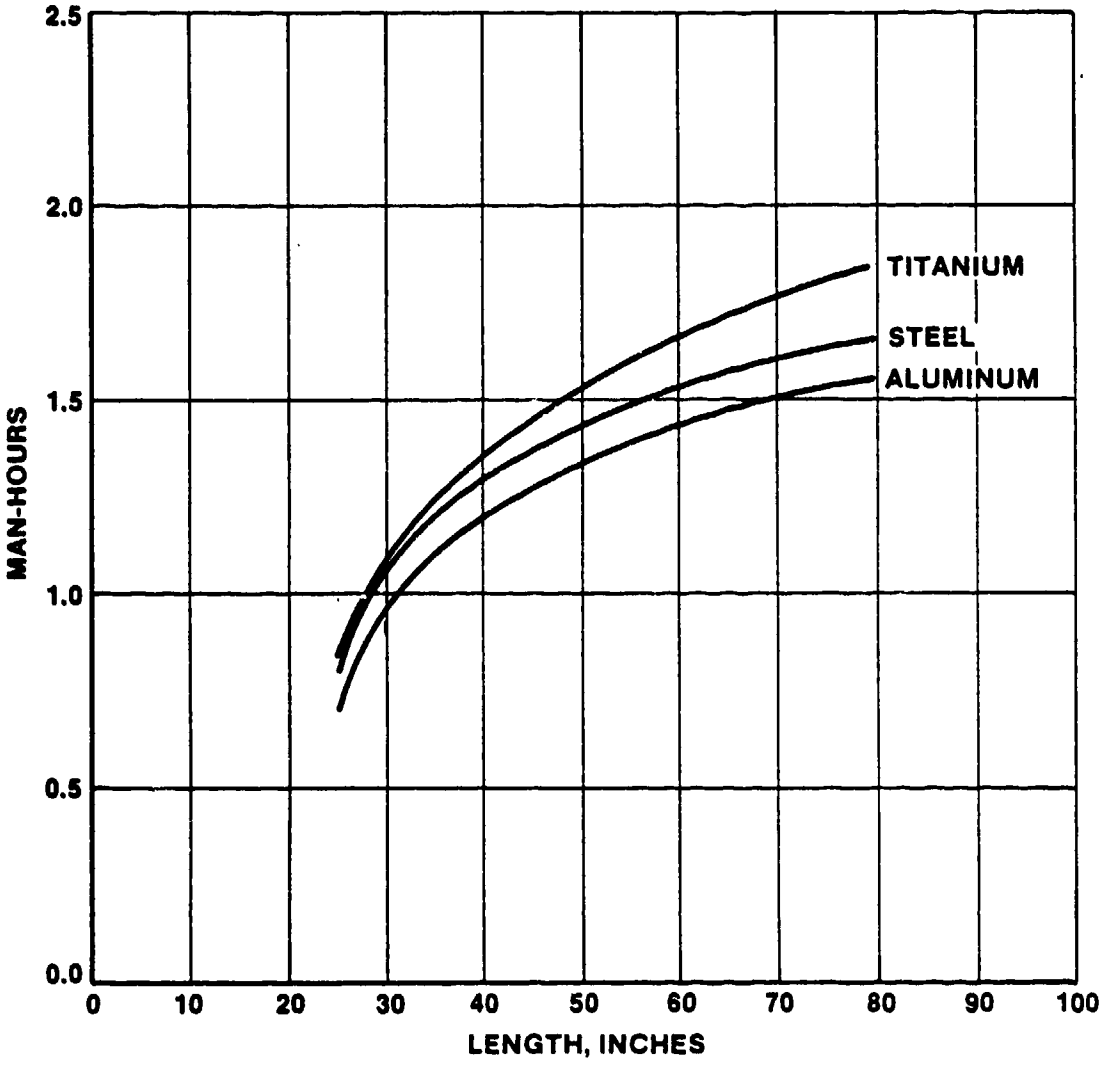
## (CHANNEL, ANGLE) BASE PART RECURRING TI&E COST




CED-TI&E-MP-M-2

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED LINEAL PARTS COMPLEX SECTIONS

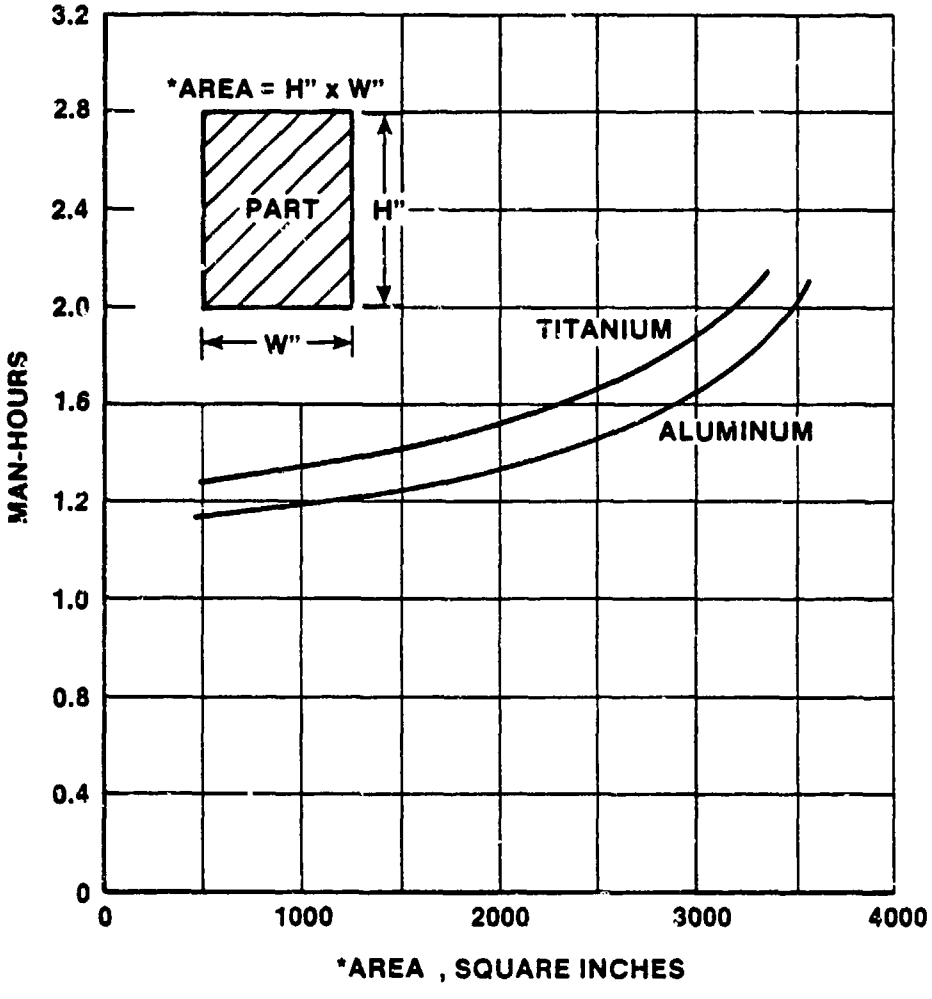
## (CRUCIFORMS, TEES) BASE PART RECURRING TI&E COST




CED-TI&E-MP-M-3

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED AREA PARTS (FRAMES, BULKHEADS, ETC.)

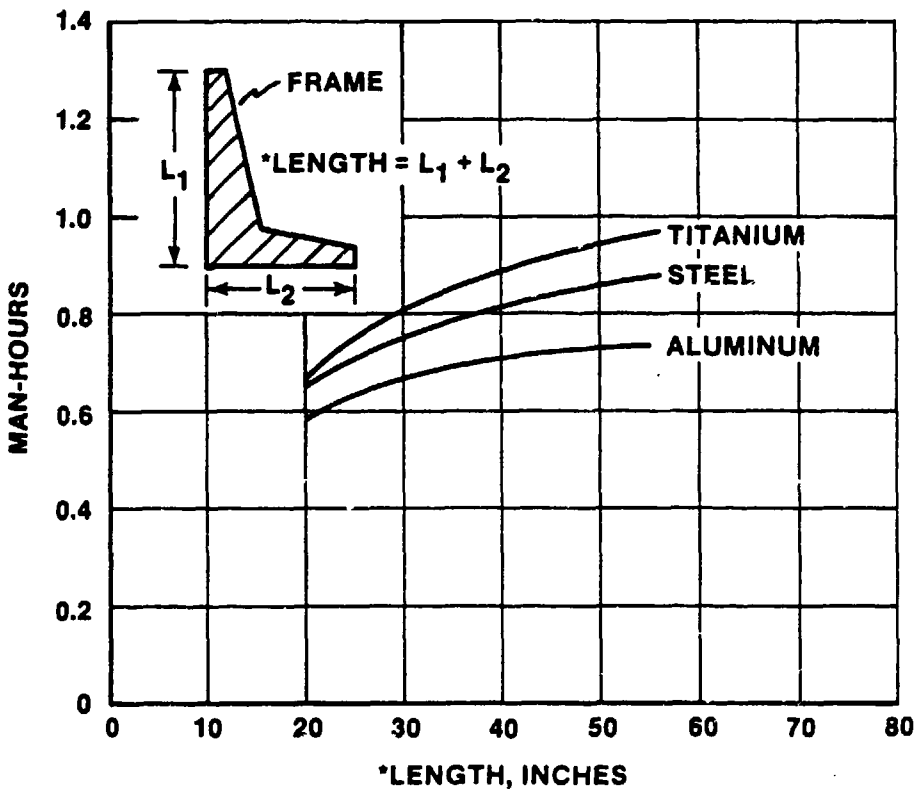
## BASE PART RECURRING TI&E COST




CED-TI&E-MP-M-4

# TEST, INSPECTION AND EVALUATION (TI&E) MACHINED FRAMES

## BASE PART RECURRING TI&E COST




CED-TI&E-MP-M-5

### 4.7.5.5 Ground Rules for Test, Inspection & Evaluation (TI&E) of Machining Section

The following General and Detailed Ground Rules for the Section on Test, Inspection & Evaluation (TI&E) of Machining were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

#### 4.7.5.5.1 General Ground Rules

The general ground rules are categorized under the following major groupings:

(a) Machined Discrete Parts
(b) Materials
(c) TI&E Methods
(d) Facilities and Equipment
(e) Data Generation - TI&E Recurring Costs
(f) Data Generation - TI&E Nonrecurring Costs
(g) Support Function Modifiers
(h) Test and Evaluation of Data.

(a) Machined Discrete Parts

(1) The machined discrete parts such as bulkheads, frames, spar caps, longerons, and small machined parts were selected as being representative of structural parts common to both small and large aircraft.

(2) The discrete parts were selected, where possible, to develop data for more than one TI&E method (coordinate 3-axis measuring machine versus manual) so as to display cost-driver effects.

(3) The selected discrete parts will be defined and dimensioned in such a manner that it will enable the TI&E effort to adequately display the effect on part cost of DICE, e.g., nondestructive testing (NDT), and tolerances.

(b) Materials

(1) The alloys selected for the discrete parts are representative of those most commonly used in the airframe industry, thereby establishing a uniform data base. The materials selected are:

- Aluminum - 2024 Plate
- Titanium - 6Al-4V Plate
- Steel - PH15-7Mo Plate.

(c) TI&E Methods

(1) Only conventional methods required to test, inspect, and evaluate the machined parts in the configurations selected will be considered.

(2) A production, in contrast to a prototype, environment will be assumed for the TI&E of machined discrete parts.

(3) To generate an effective TI&E data base for each selected part, a quality assurance operational sequence for each applicable machining method will be established. This standardized sequence will be used by each team member to determine the TI&E costs.

(d) Facilities and Equipment

(1) Only standard quality assurance facilities and equipment available to the airframe industry will be covered.

(e) Data Generation - TI&E Recurring Costs

(1) Recurring man-hour data will be generated for the TI&E in part fabrication and will, therefore, include all the TI&E functions from the release of the part to production operations through final inspection.

(2) The base part TI&E man-hours will be generated for each part.

(3) The DICE elements will be treated as separate cost elements and, therefore, not included in the TI&E base cost.

(4) The quantity for which base part and the DICE TI&E cost will be determined is at unit 200. A lot size of 25 will be applied.

(5) Cost data will be presented in man-hours.

(6) R ing tooling TI&E costs (tool maintenance, tool calibration, periodic tooling inspection, etc.) will not be included.

(7) The TI&E data submitted to BCL will be the base-part TI&E costs (standard man-hours) plus the TI&E costs (standard man-hours) of DICE associated with the discrete part design.

(8) In developing the cost data for parts, each participating company may utilize its own proprietary improvement curves.

(9) The TI&E costs (standard man-hours) as derived by each contributing team member company will be normalized by BCL to reflect an industry team average.

(10) For proprietary reasons, business sensitive information employed at team member contributing companies will not be presented in the MC/DG.

(11) No data provided by any team member will be disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(f) Data Generation - TI&E Nonrecurring Costs

(1) Tooling TI&E costs are to be developed for each part and assembly, e.g., inspection check fixtures, templates, etc.

(2) The TI&E cost of production tooling, if included, will be restricted to contract or project tools only for presentation in the MC/DG.

(3) Nonrecurring tooling cost (NRTC) generated by team companies will be normalized by BCL to reflect an industry team average.

(g) Support Function Modifiers

(1) Additional effort other than direct factory labor and TI&E will be excluded from the part cost data supplied to BCL. Other modifiers may be included later by the MC/DG user at airframe companies.

(h) Test and Evaluation of Data

(1) Test and confirmation of the formats and integrated data will be accomplished by one team member. Each of the remaining two team members will be provided with the evaluation. Any anomalies will be resolved and modifications incorporated as appropriate.

4.7.5.5.2 Detailed Ground Rules

The detailed ground rules for TI&E are categorized under the following major groupings:

(a) Materials
(b) Tolerances
(c) Discrete parts
(d) Quality control methods
(e) Inspection operations
(f) TI&E contract tooling.

(a) Materials

(1) The materials selected for the machined discrete parts are:

- Aluminum - 2024 plate
- Titanium - 6Al-4V plate
- Steel - PH15-7Mo plate.

(b) Tolerances

(1) Parts will be assumed to be manufactured to a linear tolerance of between ± 0.030" and ± 0.005" and an angular tolerance of ± 0° 30'.

(2) Surface texture is assumed to be RHR 125.

(3) The cost impact of tighter or relaxed tolerances will be addressed as a DICE element.

(c) Discrete Parts

(1) Drawings of the machined discrete parts showing configurations, dimensions, holes, trim, etc., will be established so that each team member may estimate TI&E standard hours in a consistent manner.

(2) The drawings will be depicted and dimensioned in such a manner to enable the TI&E to show cost drivers and DICE effects.

(d) Quality Control

(1) Quality control methods and types of equipment used for the TI&E of the respective parts will be specified by an operational sequence for the TI&E as well as matrices applicable to each drawing and on a data collection sheet.

(2) Where more than one TI&E method exists to inspect a discrete part, data will be generated for each method to display the comparative cost relationships.

(e) Inspection Operations

(1) The following will be typical TI&E operations that should be considered and evaluated:

- Material inspection at time of release to shop
- In-process inspection
- Nondestructive test and inspection (NDTI)
  - Magnetic particle
  - X-ray
  - Hardness test
  - Penetrant

- Ultrasonic test
- Electrical conductivity

- Surface finish and dimensional verification.

(f) TI&E Contract Tooling

(1) Each team member company will indicate, on the data collection sheets, the tooling required to inspect each discrete part.

## 4.7.6 TI&E for Composites

### 4.7.6.1 Format Selection Aid

Format selection aids are presented to provide the user with a building block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide cost-driver effects (CDE) for qualitative guidance to the lowest cost and cost-estimating data (CED) in man-hours for conducting trade-studies.

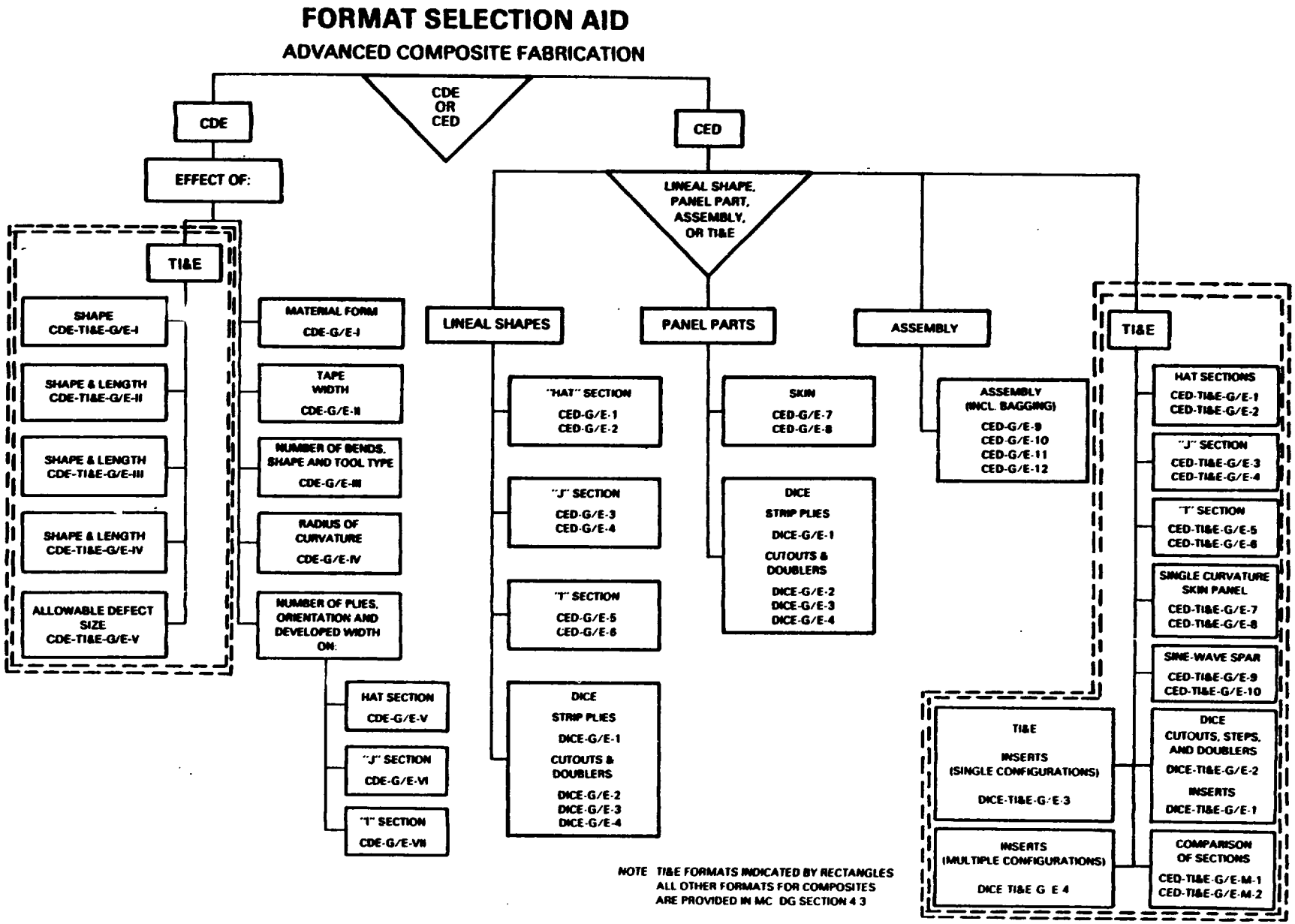

FORMAT SELECTION AID
ADVANCED COMPOSITE FABRICATION
CDE OR CED
CDE
EFFECT OF:
TI&E
SHAPE CDE-TI&E-G/E-I
SHAPE & LENGTH CDE-TI&E-G/E-II
SHAPE & LENGTH CDE-TI&E-G/E-III
SHAPE & LENGTH CDE-TI&E-G/E-IV
ALLOWABLE DEFECT SIZE CDE-TI&E-G/E-V
MATERIAL FORM CDE-G/E-I
TAPE WIDTH CDE-G/E-II
NUMBER OF BENDS, SHAPE AND TOOL TYPE CDE-G/E-III
RADIUS OF CURVATURE CDE-G/E-IV
NUMBER OF PLIES, ORIENTATION AND DEVELOPED WIDTH ON:
HAT SECTION CDE-G/E-V
"J" SECTION CDE-G/E-VI
"T" SECTION CDE-G/E-VII
CED
LINEAL SHAPE, PANEL PART, ASSEMBLY, OR TI&E
LINEAL SHAPES
"HAT" SECTION CED-G/E-1 CED-G/E-2
"J" SECTION CED-G/E-3 CED-G/E-4
"T" SECTION CED-G/E-5 CED-G/E-6
DICE STRIP PLIES DICE-G/E-1 CUTOUTS & DOUBLERS DICE-G/E-2 DICE-G/E-3 DICE-G/E-4
PANEL PARTS
SKIN CED-G/E-7 CED-G/E-8
DICE STRIP PLIES DICE-G/E-1 CUTOUTS & DOUBLERS DICE-G/E-2 DICE-G/E-3 DICE-G/E-4
ASSEMBLY
ASSEMBLY (INCL. BAGGING) CED-G/E-9 CED-G/E-10 CED-G/E-11 CED-G/E-12
TI&E
HAT SECTIONS CED-TI&E-G/E-1 CED-TI&E-G/E-2
"J" SECTION CED-TI&E-G/E-3 CED-TI&E-G/E-4
"T" SECTION CED-TI&E-G/E-5 CED-TI&E-G/E-6
SINGLE CURVATURE SKIN PANEL CED-TI&E-G/E-7 CED-TI&E-G/E-8
SINE-WAVE SPAR CED-TI&E-G/E-9 CED-TI&E-G/E-10
DICE CUTOUTS, STEPS, AND DOUBLERS DICE-TI&E-G/E-2
INSERTS DICE-TI&E-G/E-1
COMPARISON OF SECTIONS CED-TI&E-G/E-M-1 CED-TI&E-G/E-M-2
TI&E INSERTS (SINGLE CONFIGURATIONS) DICE-TI&E-G/E-3
INSERTS (MULTIPLE CONFIGURATIONS) DICE TI&E G E 4
NOTE TI&E FORMATS INDICATED BY RECTANGLES ALL OTHER FORMATS FOR COMPOSITES ARE PROVIDED IN MC DG SECTION 4 3

FIGURE 4.7.6-1

4.7.6.2 Composite Parts Analyzed

Composite lineal shapes, panels and a sine-wave shear-web typical of a rib or spar, were analyzed to provide man-hour data to the designer to test, inspect and evaluate. These structural elements are shown in Figures 4.7.8-2 to 4.7.8-4.

# COMPOSITE LINEAL SHAPES USED TO DEVELOP FORMATS (INFORMATION ONLY)

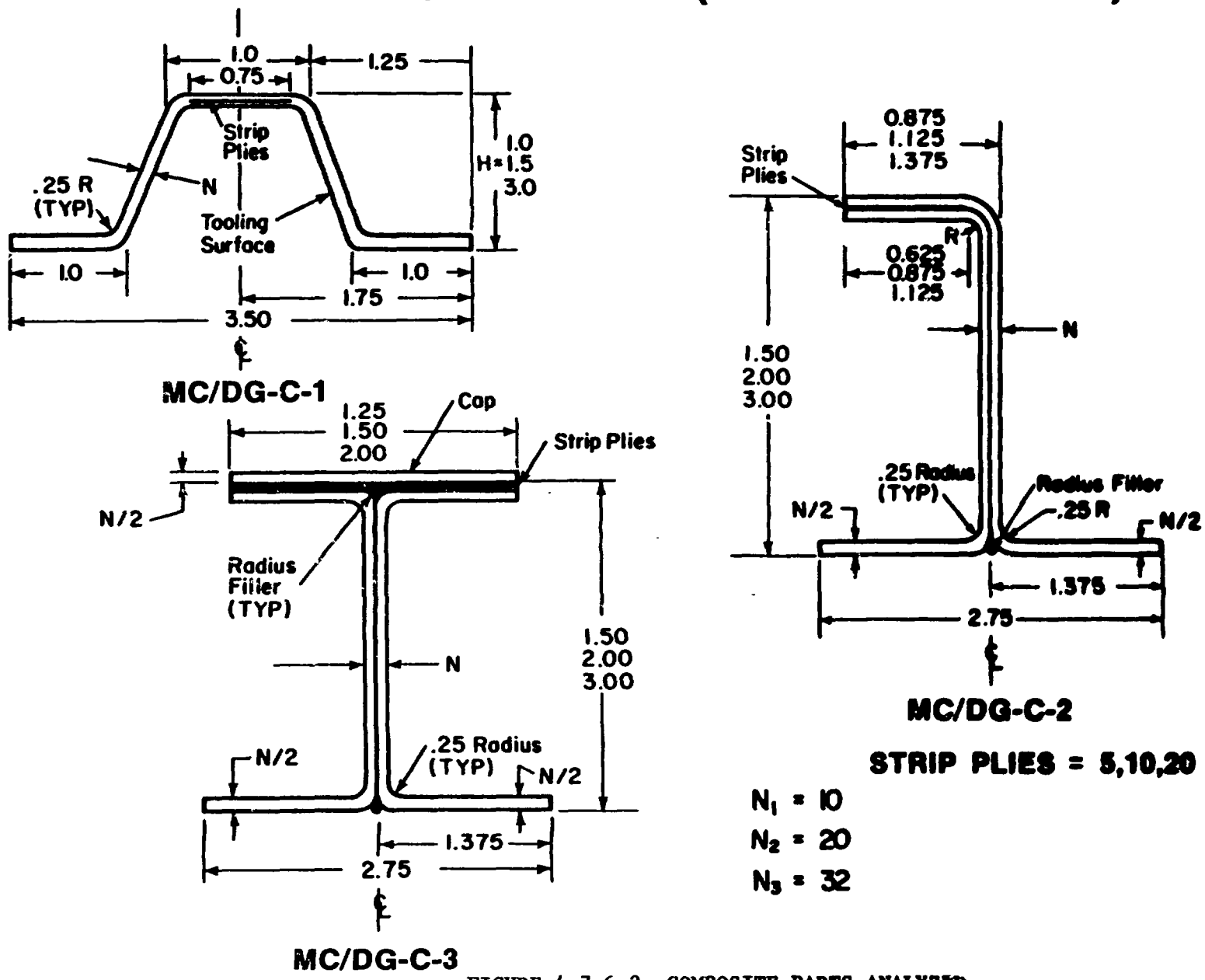



FIGURE 4.7.6-2 COMPOSITE PARTS ANALYZED

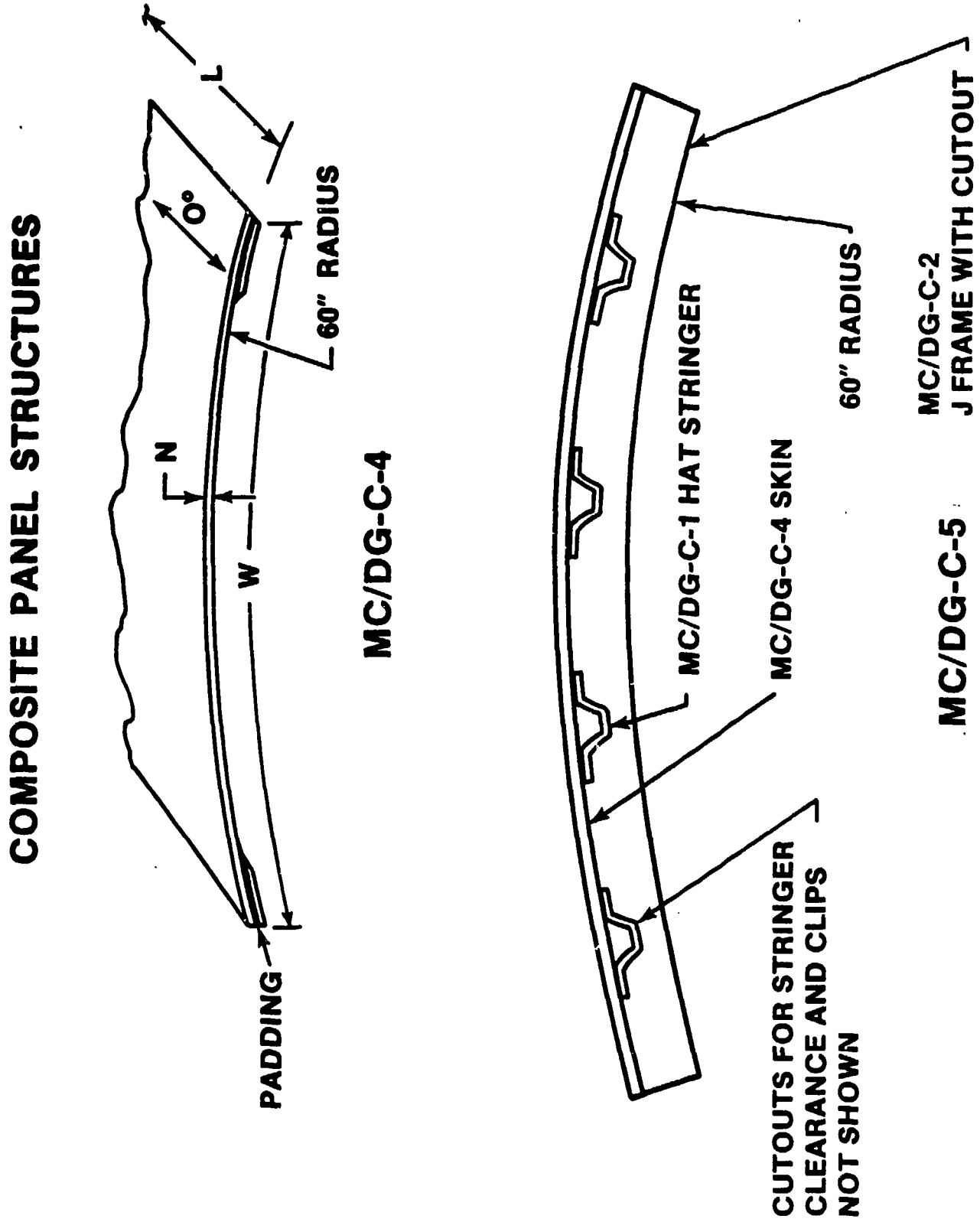



FIGURE 4.7.6-3. COMPOSITE PARTS ANALYZED

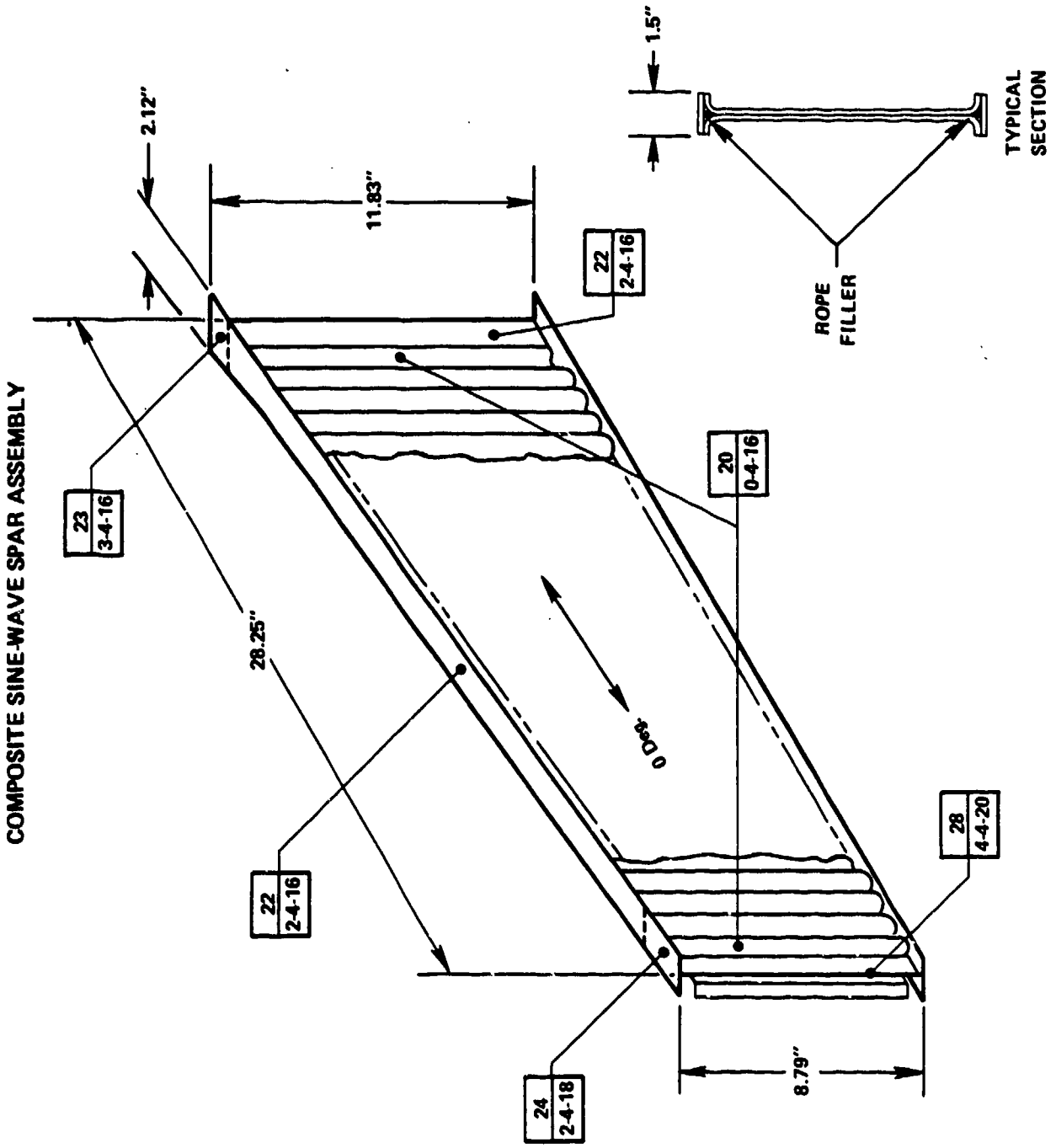
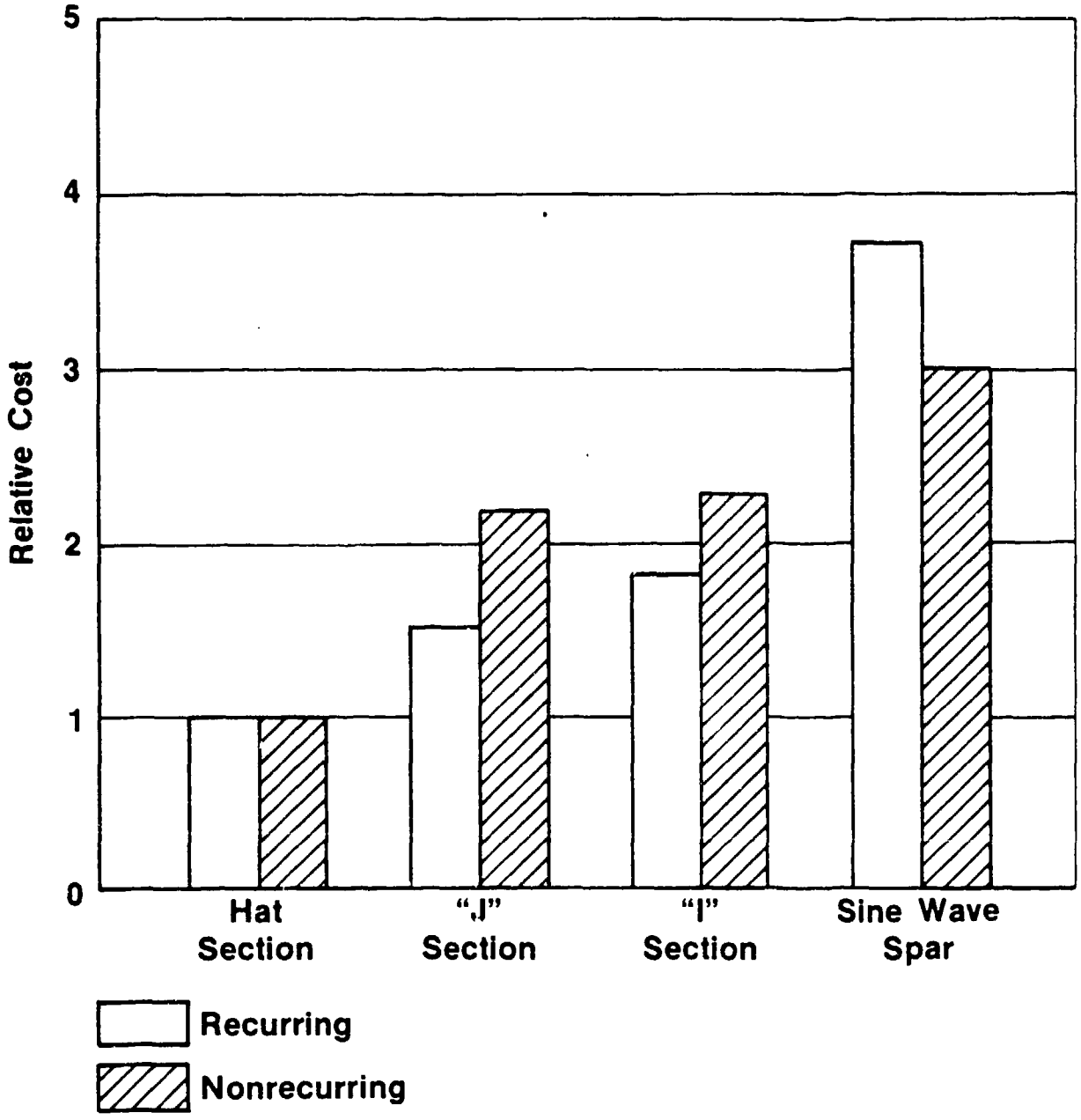



FIGURE 4.7.6-4. COMPOSITE PART ANALYZED

### 4.7.6.3 TI&E Data for Composites

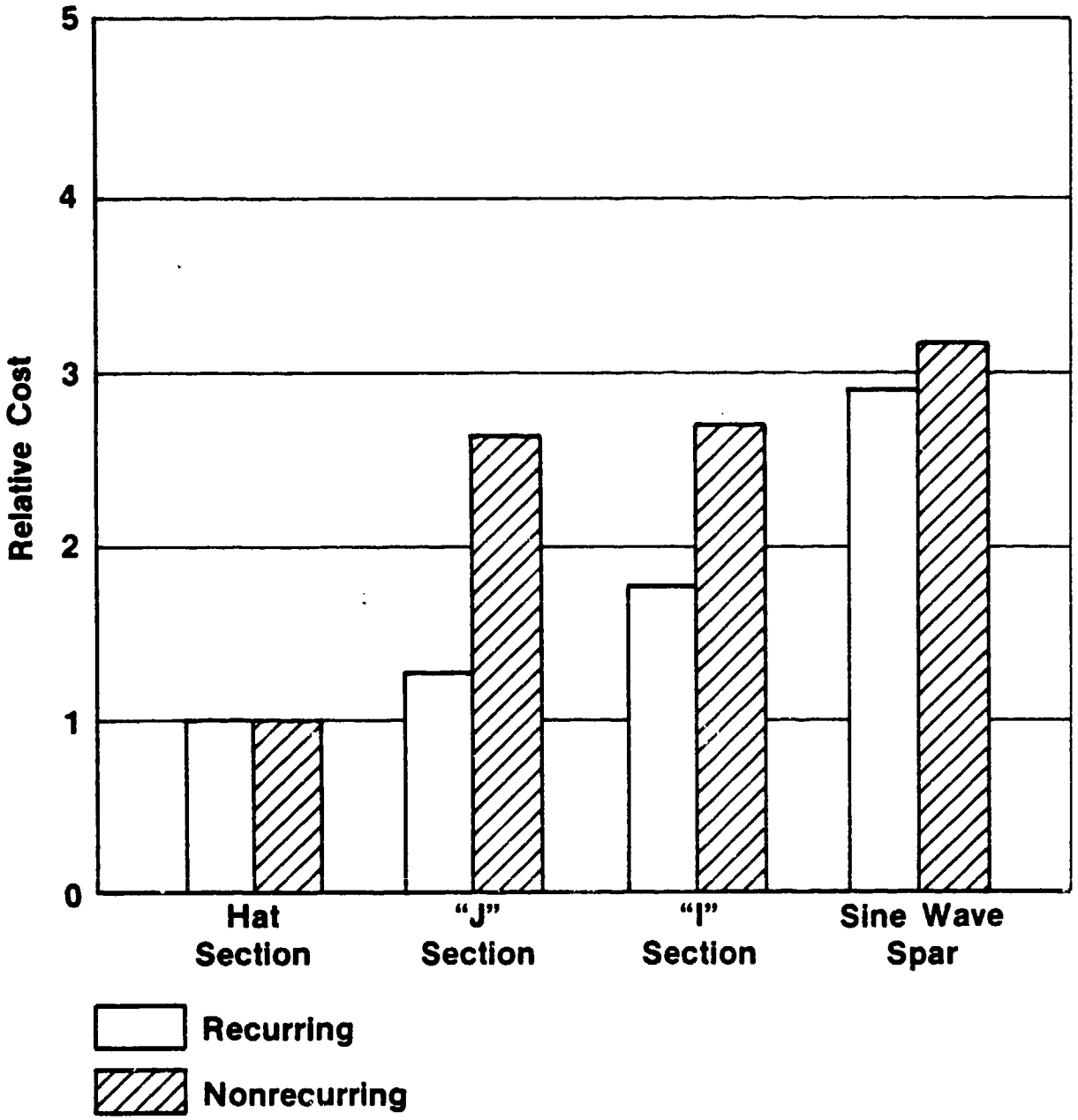
The man-hours required to conduct TI&E on the composite structural elements shown in Figures 4.7.6-2 to 4.7.6-4 are presented using the formats on the following pages.

# TEST, INSPECTION AND EVALUATION (TI&E) ADVANCED COMPOSITES EFFECT OF SHAPE ON RECURRING AND NONRECURRING TI&E COST



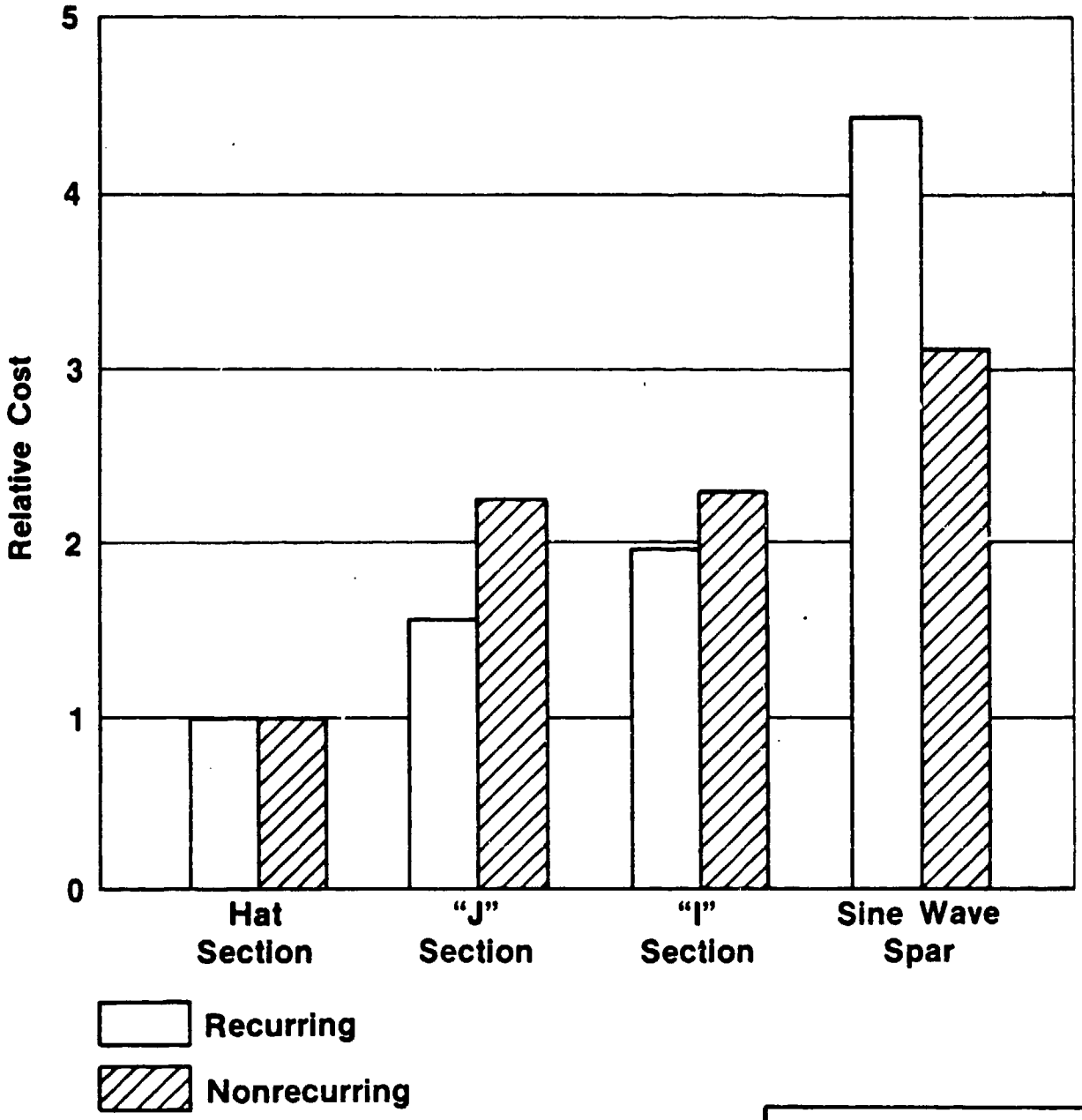

CDE-TI&E-G/E-I

# TEST, INSPECTION AND EVALUATION (TI&E) ADVANCED COMPOSITES EFFECT OF SHAPE ON RECURRING AND NONRECURRING TI&E COST 2 FOOT SECTION



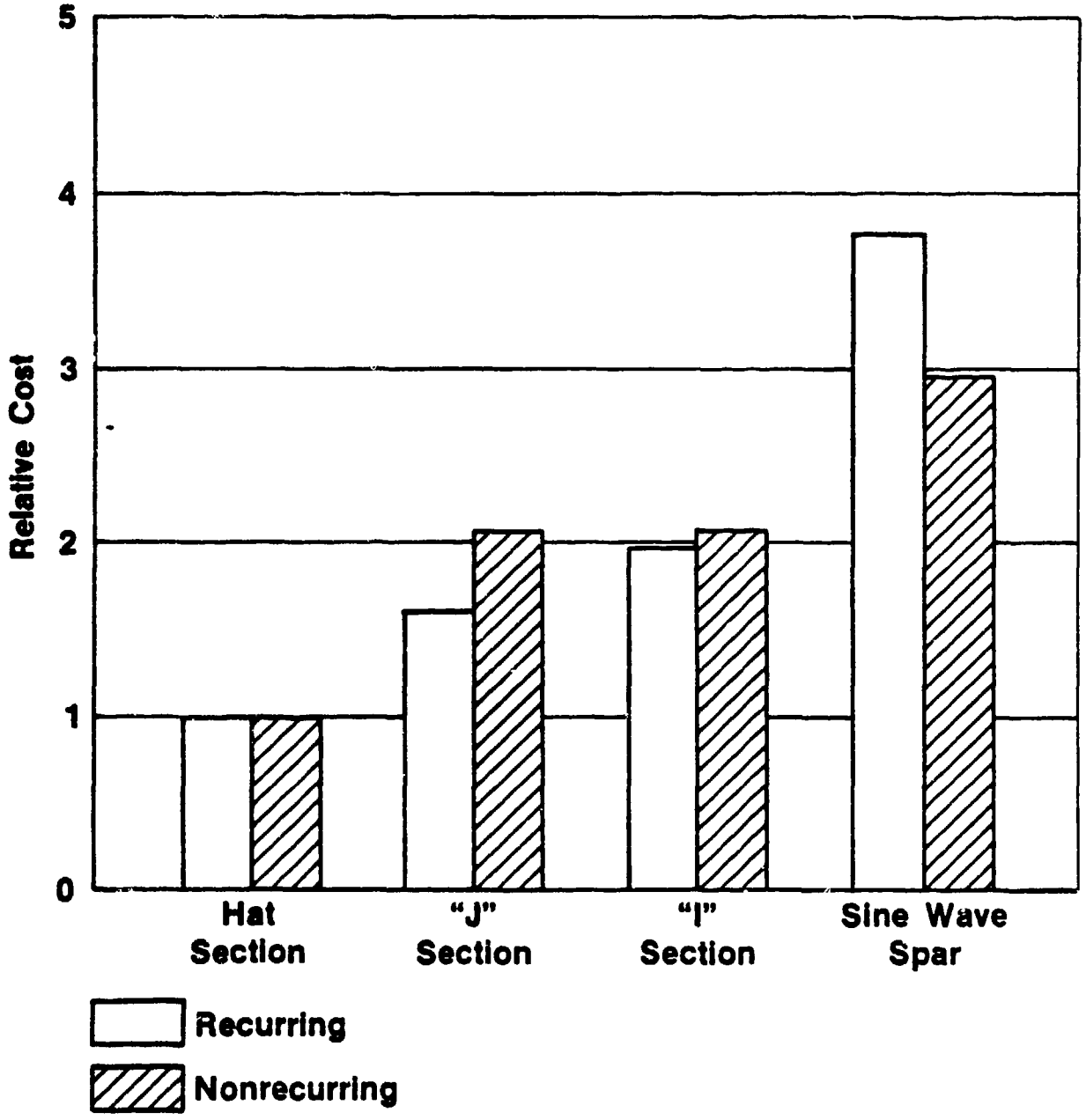

CDE-TI&E-G/E-II

# TEST, INSPECTION AND EVALUATION (TI&E) ADVANCED COMPOSITES EFFECT OF SHAPE ON RECURRING AND NONRECURRING TI&E COST 8 FOOT SECTION



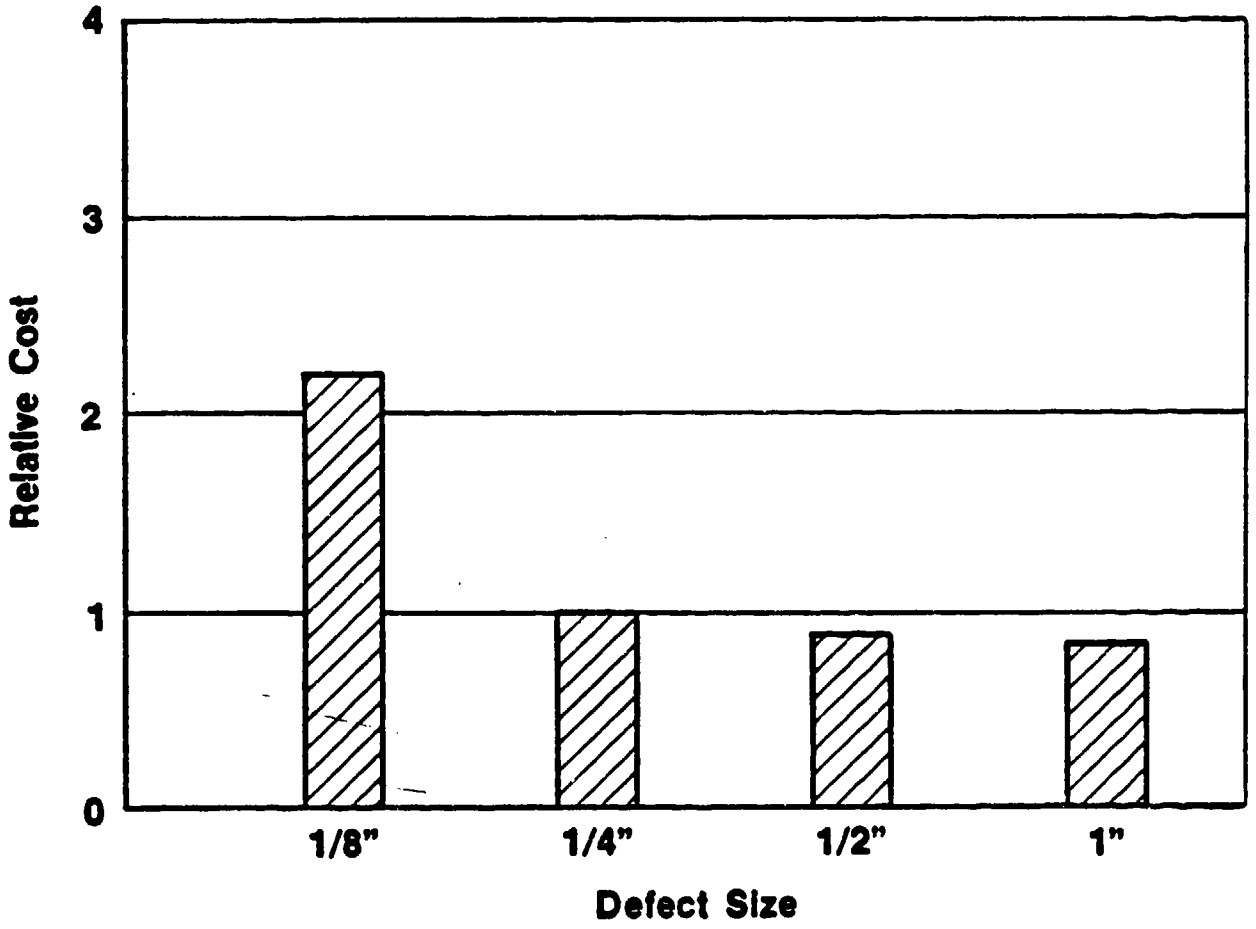

CDE-TI&E-G/E-III

# TEST, INSPECTION AND EVALUATION ADVANCED COMPOSITES EFFECT OF SHAPE ON RECURRING AND NONRECURRING TI&E COST 12 FOOT SECTION



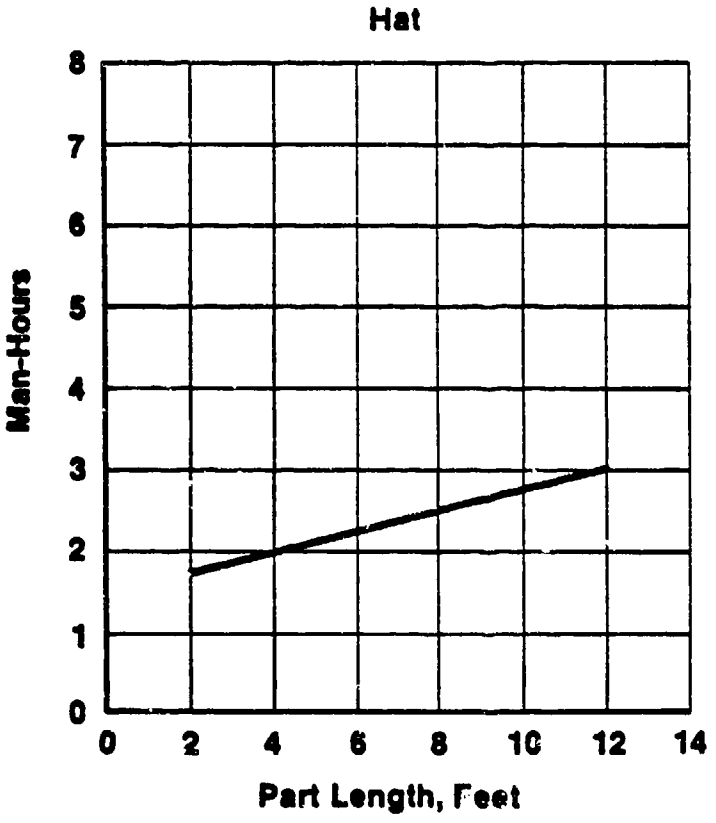

CDE-TI&E-G/E-IV

# TEST, INSPECTION AND EVALUATION (TI&E) ADVANCED COMPOSITES EFFECT OF MAXIMUM ALLOWABLE DEFECT SIZE ON TI&E COST




CDE-TI&E-G/E-V

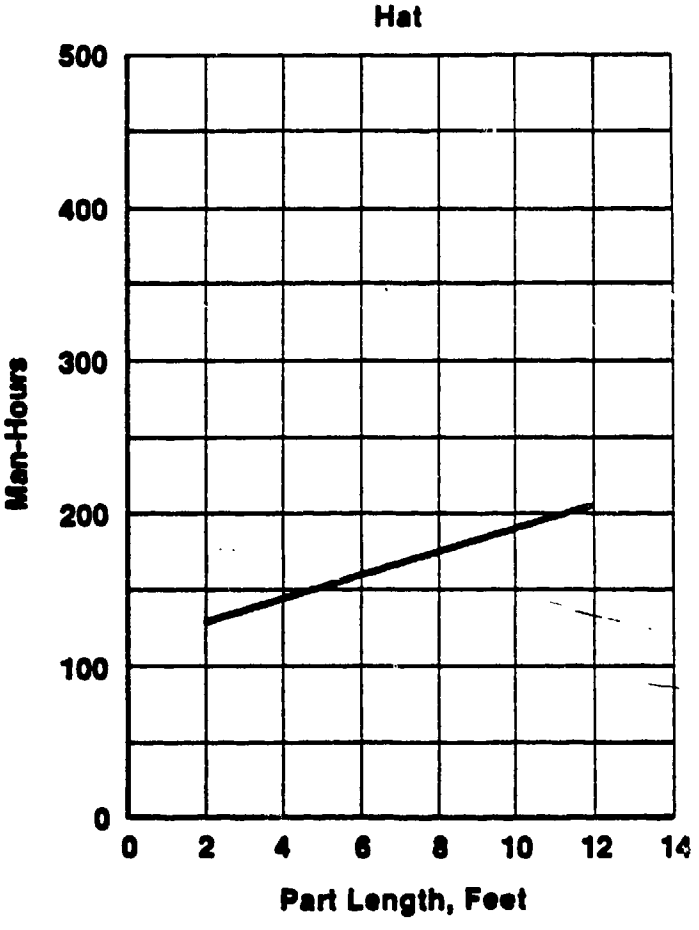
# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE HAT SECTION RECURRING COST/PART




- Applies to laminates up to 32 plies.

CED-TI&E-G/E-1

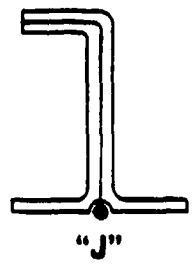
# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE HAT SECTION NONRECURRING COST/PART

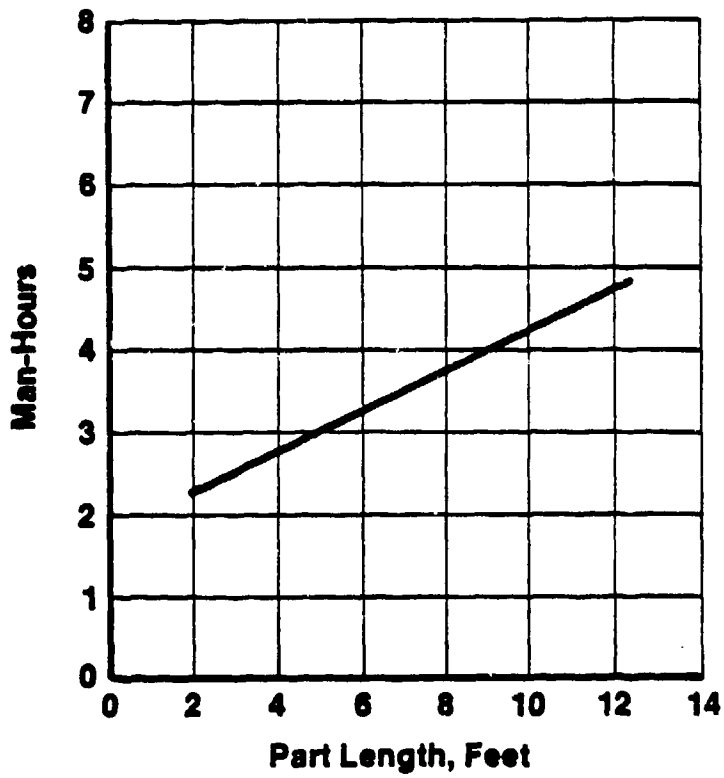



- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.

**CED-TI&E-G/E-2**

# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "J" SECTION RECURRING COST/PART

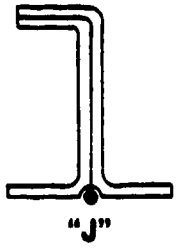


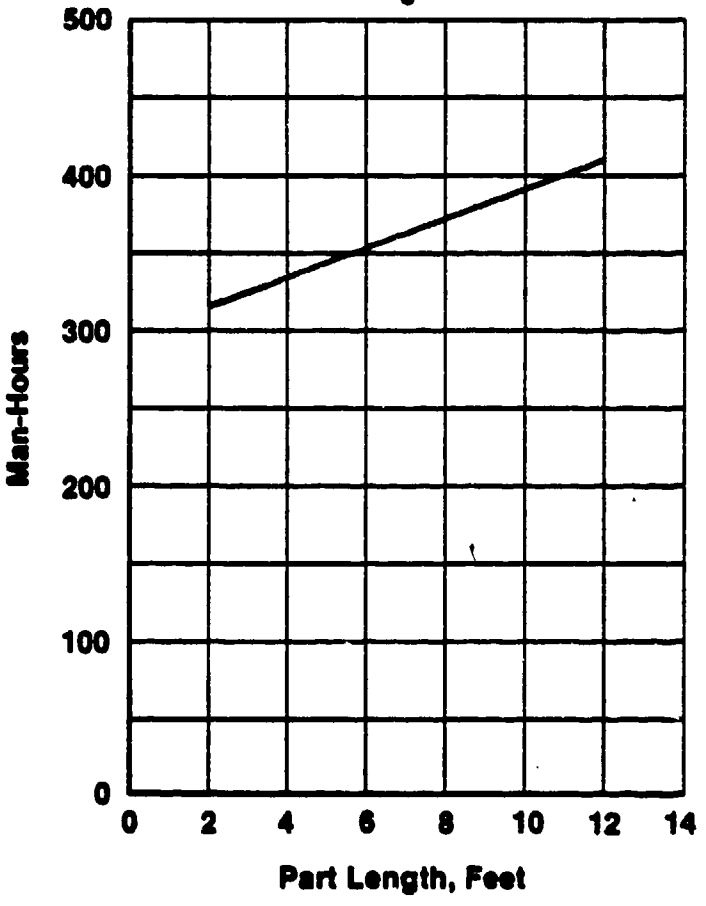




- Applies to laminates up to 32 plies.

**CED-TI&E-G/E-3**

# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "J" SECTION NONRECURRING COST/PART

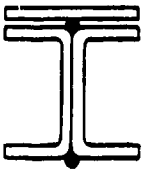


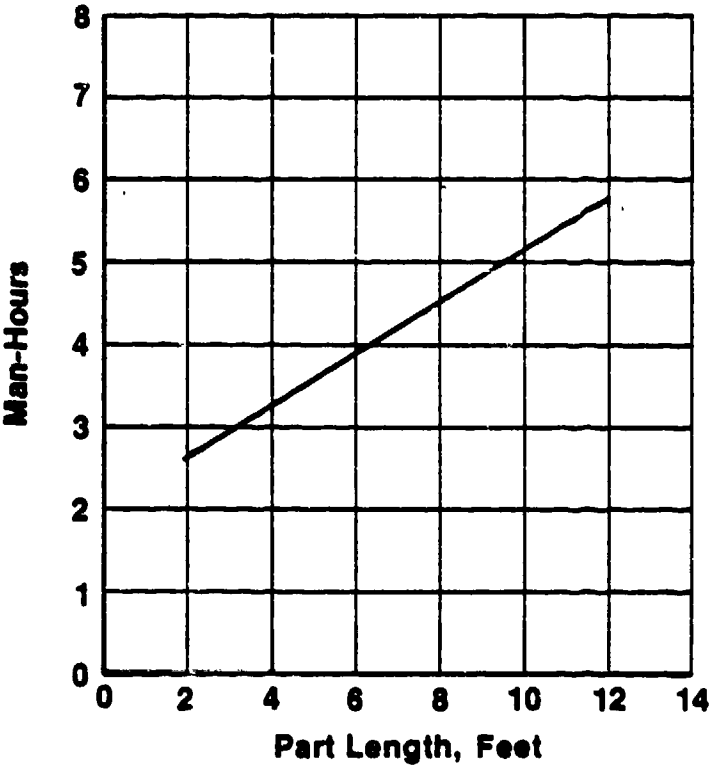

- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.

CED-TI&E-G/E-4

# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "I" SECTION RECURRING COST/PART



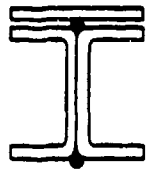
"I"



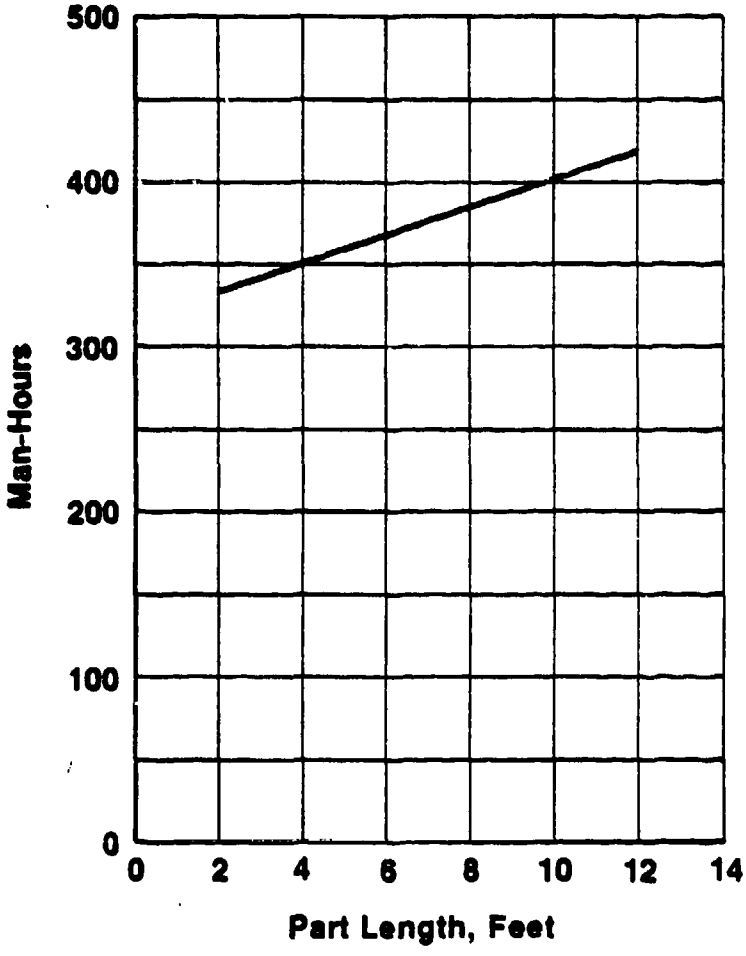

- Applies to laminates up to 32 plies.

CED-TI&E-G/E-5

# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "I" SECTION NONRECURRING COST/PART



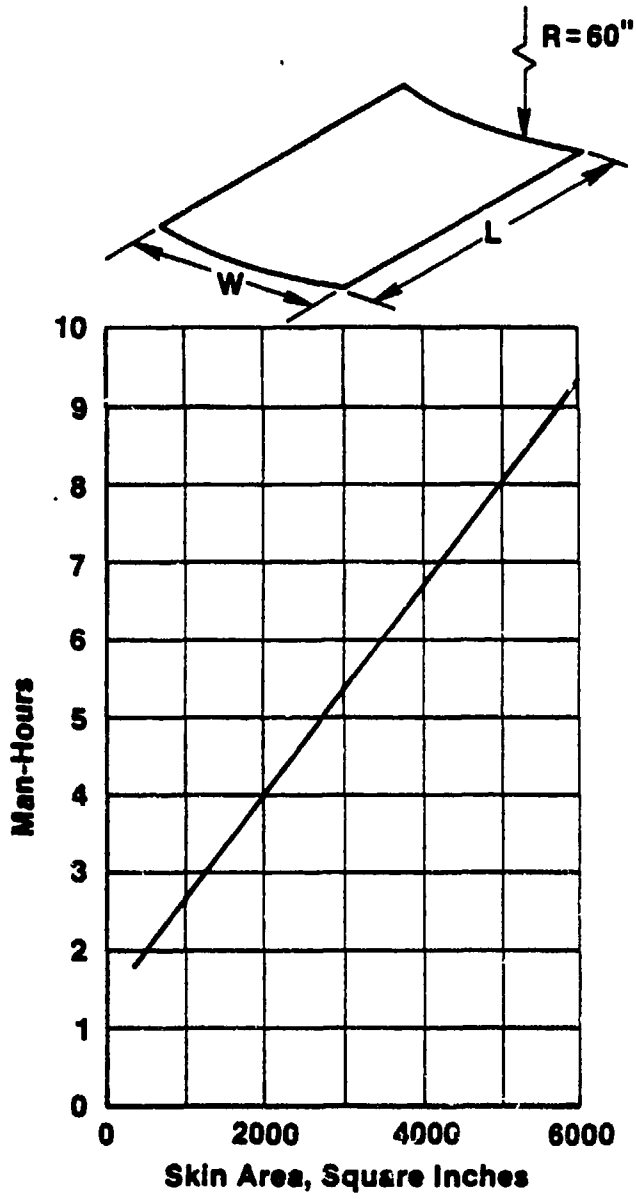
"I"




- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.

CED-TI&E-G/E-6

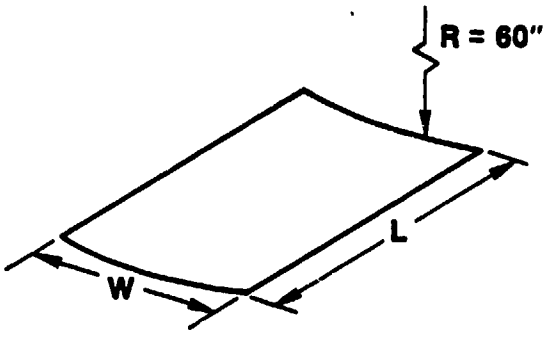
# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE SINGLE CURVATURE SKIN RECURRING COST/PART

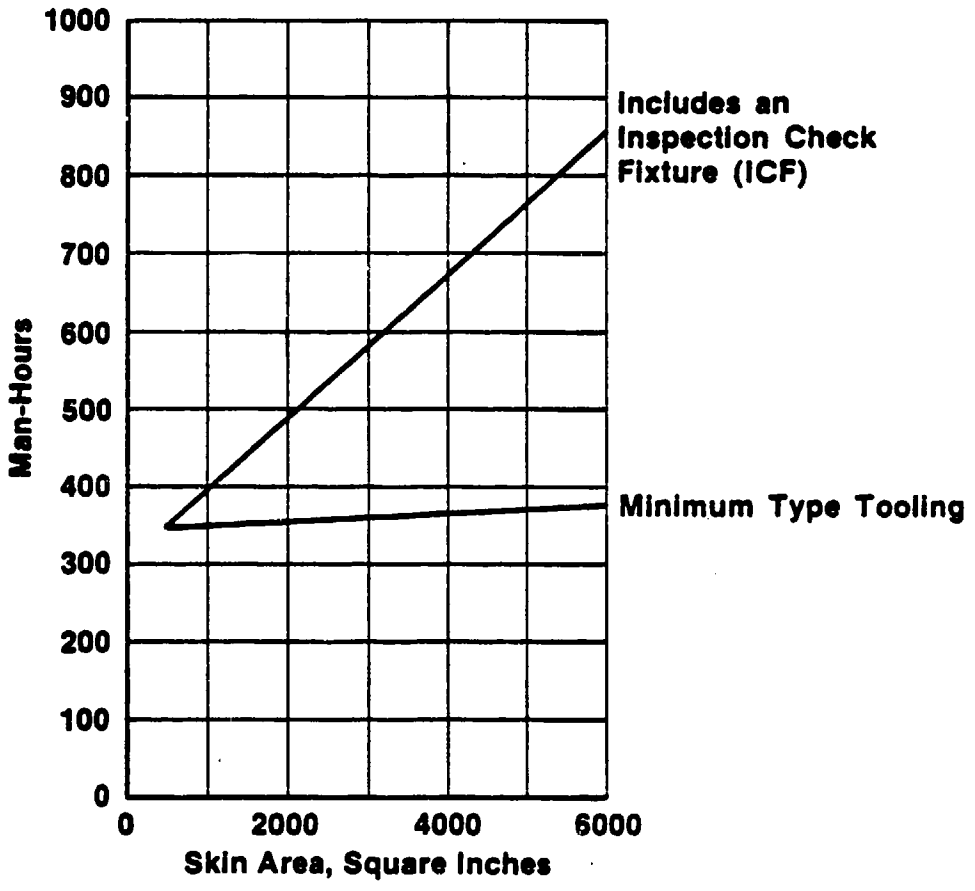



- Applies to laminates up to 24 plies.

CED-TI&E-G/E-7

# TEST, INSPECTION, AND EVALUATION (TI&E) COMPOSITE SINGLE CURVATURE SKIN NONRECURRING COST/PART

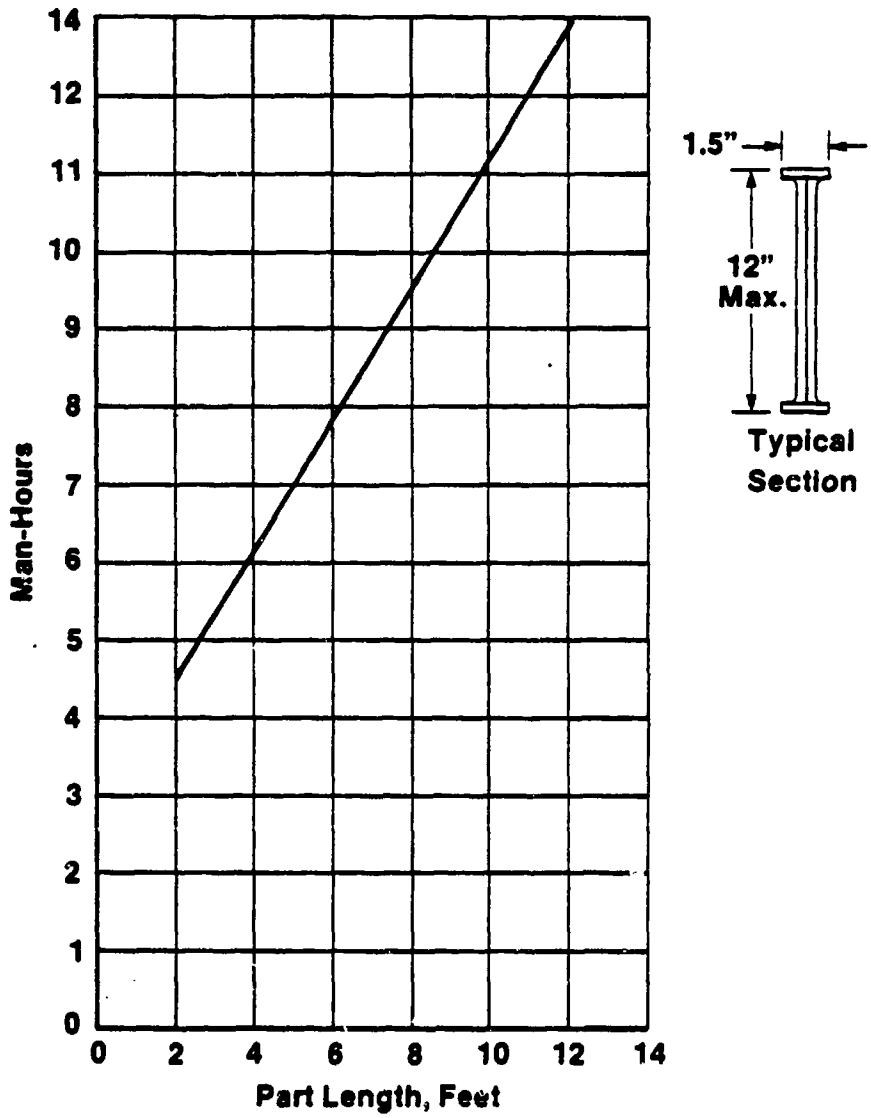



- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.

CED-TI&E-G/E-8

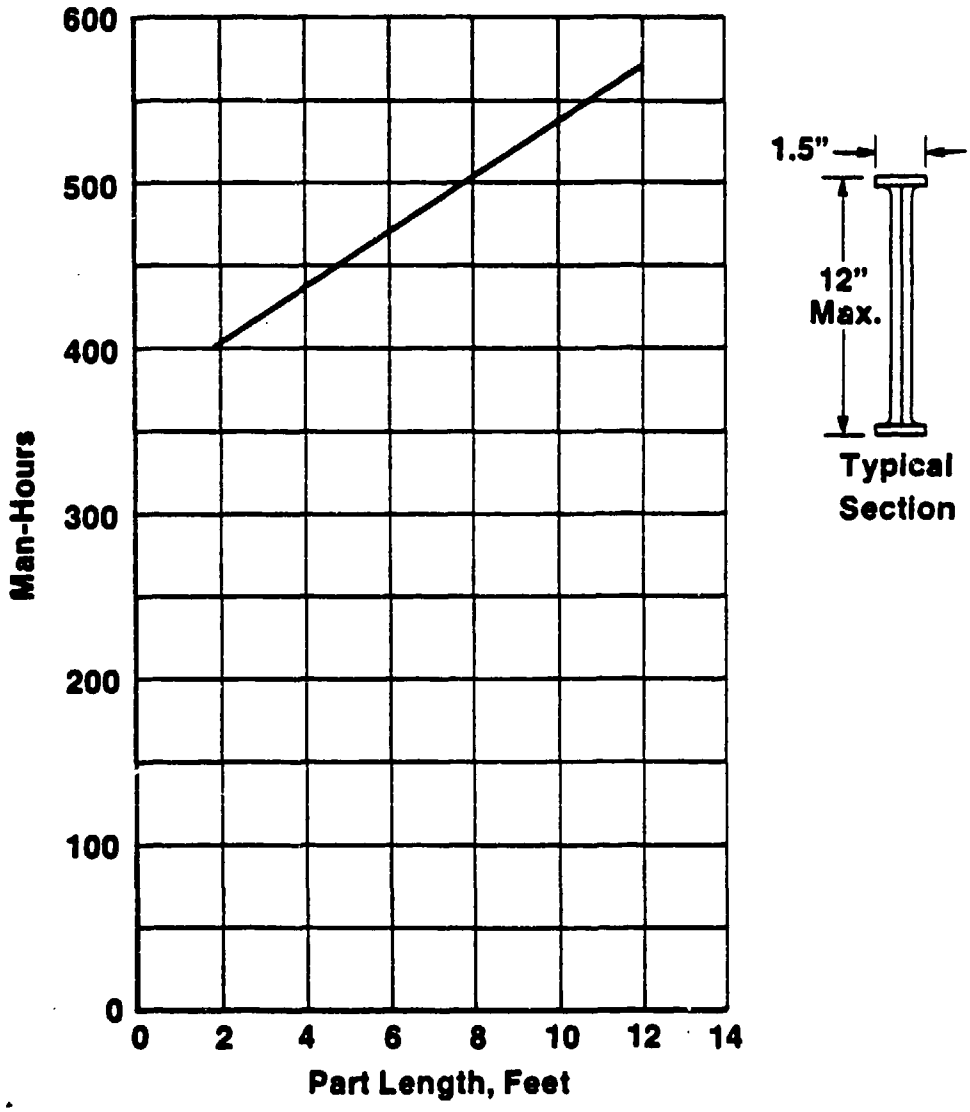
# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE SINE-WAVE SPAR RECURRING COST/PART




- Applies to laminates up to 24 plies.

**CED-TI&E-G/E-9**

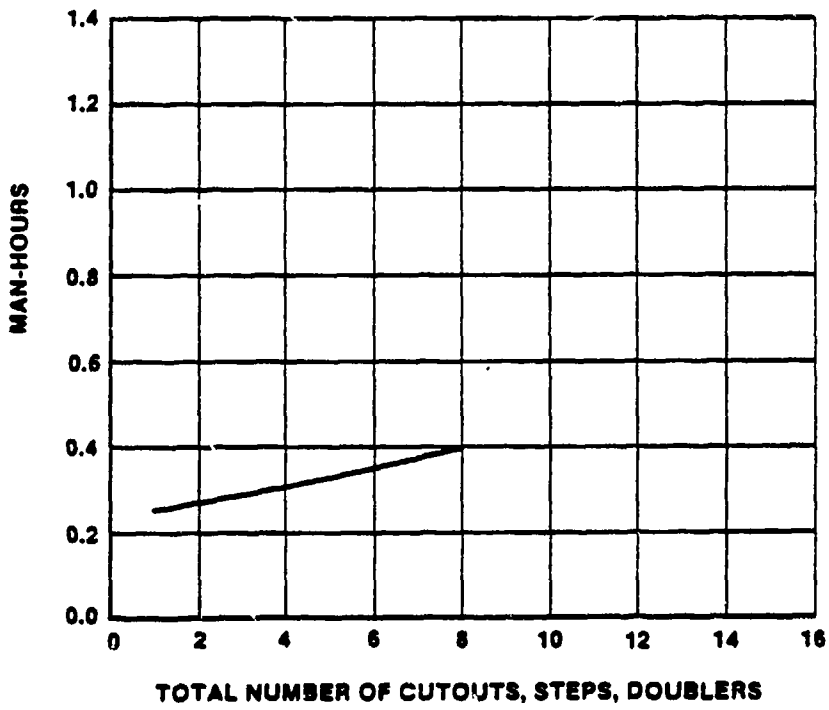
# TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE SINE-WAVE SPAR NONRECURRING COST/PART




CED-TI&E-G/E-10

# TEST, INSPECTION AND EVALUATION (TI&E) ADVANCED COMPOSITES

## RECURRING COST/PART FOR TI&E OF CUTOUTS, STEPS, AND DOUBLERS IN SINGLE CONFIGURATION APPLICATIONS



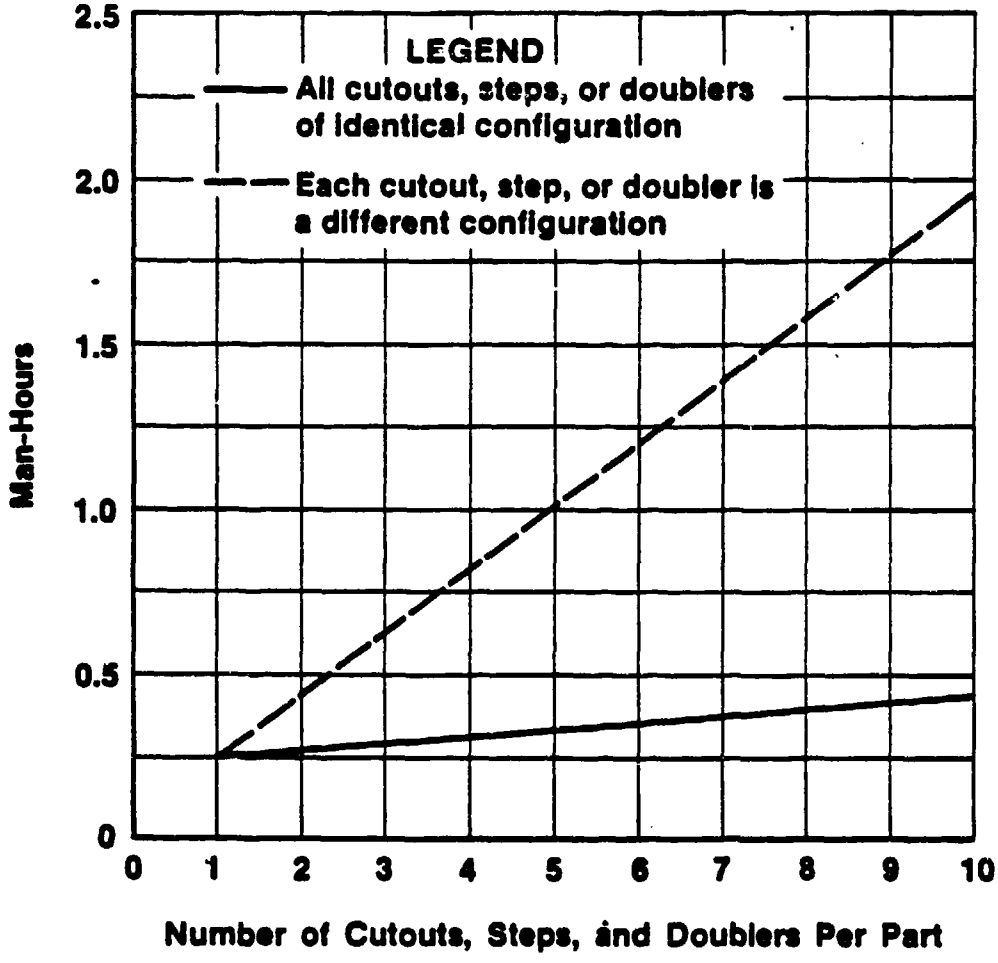

**ASSUMPTIONS**

(A) EACH CUTOUT, STEP, OR DOUBLER IS OF A SIMILAR CONFIGURATION
(B) EACH CUTOUT, STEP, OR DOUBLER EXCEEDS BASE CONFIGURATION BY FOUR PLIES
(C) PART REPOSITIONING NOT REQUIRED FOR NDT OF DICE
(D) SIZE AND CONFIGURATION OF PART DO NOT SIGNIFICANTLY AFFECT DICE MAN-HOURS
(E) HOURS SHOWN ARE THE INCREASE OVER A BASE PART WITHOUT DICE

DICE-TI&E-G/E-1

# TEST, INSPECTION AND EVALUATION (TI&E) ADVANCED COMPOSITES

## RECURRING COST/PART FOR CUTOUTS, STEPS, AND DOUBLERS




DICE-TI&E-G/E-2

### 4.7.6.4 Ground Rules for Test, Inspection & Evaluation (TI&E) of Advanced Composites Section

The following General and Detailed Ground Rules for the Section on Test, Inspection & Evaluation (TI&E) of Advanced Composites were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

#### 4.7.6.4.1 General Ground Rules

The general ground rules are categorized under the following major groupings:

(a) TI&E general and detail ground rules will be based on ground rules developed for the "MC/DG Advanced Composite Demonstration Section"

(b) TI&E Technologies

(c) TI&E Facilities and Equipment

(d) Data Generation - TI&E Recurring Costs

(e) Data Generation - TI&E Nonrecurring Costs.

(a) See "Ground Rules for Advanced Composite Fabrication Demonstration Section" in Appendix F of Volume II of MC/DG Final Report (AFWAL-TR-80-4115).

(b) TI&E Technologies

(1) Only conventional TI&E technologies, such as covered in the "Advanced Composites Fabrication Guide" (ACFG) are to be considered. No emerging TI&E methods are to be considered.

(2) A production environment, in contrast to a prototype, is assumed for the advanced composite parts based on 200 units.

(3) To generate an effective data base for each selected part, a factory operational sequence for the selected manufacturing method, processes, and associated TI&E

operations will be established. This standardized sequence will be used by each assigned team member to determine the TI&E cost, wherever possible.

(c) Facilities and Equipment

(1) Only standard manufacturing and TI&E facilities, currently available to the airframe industry, will be considered.

(d) Data Generation - Recurring Costs

(1) Recurring man-hour data will be generated for the complete TI&E process to include all hands-on-direct operations from receipt of the raw material to a finished part and/or assembly.

(2) The TI&E costs will be generated for each part type. These costs will represent the sum of all standard hours associated with each part as specified in these ground rules.

(3) Designer-influenced cost elements (DICE) requiring additional operations will be treated as separate cost elements.

(4) The resulting TI&E cost drivers will be identified.

(5) Cost data will be expressed in standard man-hours.

(6) A lot size of 25 will be utilized.

(7) Recurring tooling inspection costs will not be included.

(8) In developing cost data for TI&E, individual team company learning curves will be used, if available. Unit costs will be evaluated at unit 200 (cumulative average).

(9) The TI&E cost, as derived by each contributing airframe company, will be normalized by BCL to reflect an industry team average value for each part.

(10) For proprietary reasons, business-sensitive information employed at team member contributing companies will not be presented in the MC/DG.

(11) No data provided by any airframe company team member will be disclosed to other team members, agencies, or to the public without the expressed approval of the contributing team member.

(12) Recurring TI&E costs included will be based on manufacturing and quality assurance functions and sequence as referenced in the MC/DG Demonstration Section, Appendix F (MC/DG Final Report; AFWAL-TR-80-4115).

(e) Data Generation - TI&E Nonrecurring Costs

(1) The tooling TI&E costs are to be generated for each part and assembly, e.g., inspection, check fixtures, templates, etc.

(2) Nonrecurring costs generated by the team member companies will be normalized by BCL for presentation in the MC/DG.

4.7.6.4.2 Detailed Ground Rules

The detailed ground rules are categorized under the following major groupings:

(a) Material TI&E

(b) Base part drawings and sketches used to develop cost data for formats. See Appendix I (MC/DG Final Report)

(c) Tolerances

(d) Estimating method.

(a) Material TI&E

(1) Chemical analysis

(2) Mechanical properties

(3) Age history

(4) Dimensional check

(5) Fiber volume

(6) Thickness per ply

(7) Cure characterization

(8) Delamination checks

(9) Nondestructive testing (NDT)

(10) In-process controls.

(b) Parts and Assemblies

(1) Use parts depicted in MC/DG for composites, but also include the sine-wave spar.

(c) Tolerances

(1) Tolerances for the base part configurations were considered to be: ± 0.03 inch on lineal dimensions and ± 0.00025 inch on thickness per ply.

(2) Tolerance for the cocured assembly will be ± 0.06 inch on part location.

(3) A minimum of 0.25 inch will be used on all interior radii.

(4) Fit-up maximum tolerances for cured details will be 0.030 inch gap for "Mechanically Fastened Assembly" and 0.015 inch for bonded assemblies.

(5) Maximum delamination size.

## 4.8 Integrated Trade-Off Studies Using MC/DG

The primary objectives of the integrated trade-offs were to:

- Demonstrate the use of the MC/DG in an industrial environment designing typical airframe structures
- Determine whether the manufacturing cost (man-hour) formats meet the format development criteria established
- Determine whether the formats provide the accuracy required by designers to conduct realistic comparisons of airframe configurations in both metallic and composite materials.

### 4.8.1 Scope of Trade-Off Studies

This section describes examples of integrated cost trade-offs using the sheet metal, mechanically fastened assemblies, and advanced composite manufacturing man-hour data in MC/DG Sections 4.1, 4.2, and 4.3. These examples were selected as being representative of actual design problems on aircraft in the current and future Air Force inventories.

The trade-offs are described in the following sections of Volume III of the User's Manual FTR450261000U. The materials studied and also the aerospace coalition members that conducted the studies in their design departments, are indicated below:

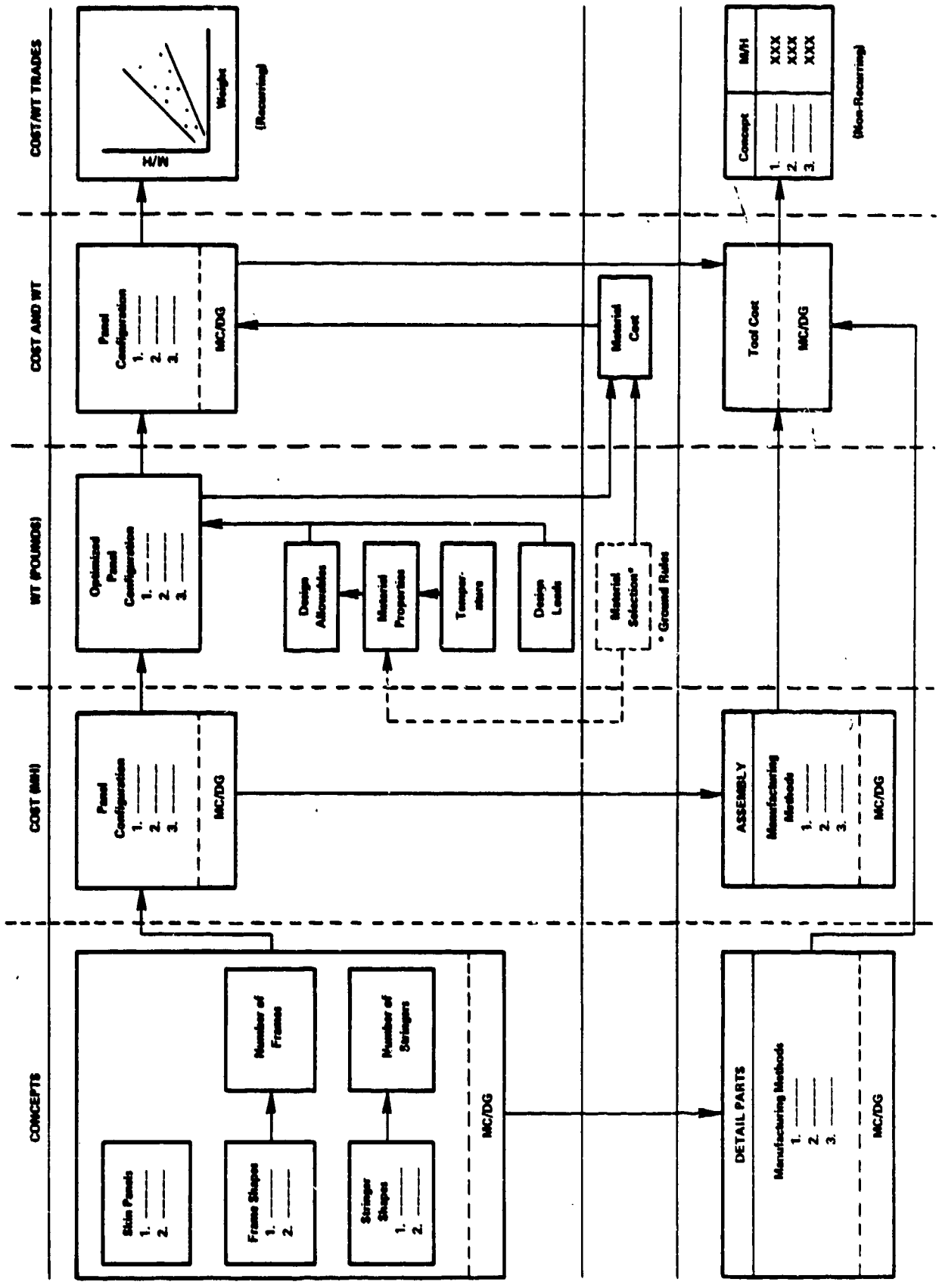
Section 4.8.2: General Dynamics Corporation, Fort Worth Division--aluminum alloy panels

Section 4.8.3: Lockheed-California Company--titanium alloy panels

Section 4.8.4: Rockwell International, Los Angeles Division--graphite/epoxy panels.

While each company utilized its own design approaches and procedures, the following flow diagram, Figure 4.8-1, illustrates the generic approach of conducting the trade-offs. The use of the MC/DG at various decision points is indicated on this figure.

FIGURE 4.8-1. TRADE-STUDY FLOW DIAGRAM



### 4.8.2 Aluminum Fuselage Panel

This section presents the methodology and results of the trade-offs conducted on the aluminum fuselage panel. The approach used can be summarized in four steps. First, a basic panel was defined. Next, structural concepts were developed as candidate for the panel designs. Third, the ground rules and assumptions for the study were specified. Fourth, the MC/DG data display formats were utilized to obtain the cost of the concepts.

The panel chosen for this trade-off is from the fuselage of the Air Force F-16 aircraft. Figure 4.8-2 shows the location of the panel on this aircraft. The designations and sketches of the fuselage panel concepts are shown in Figure 4.8-3. In the designations, "S" refers to single curvature and "C" to compound curvature. The details of the panel concepts selected for evaluation are illustrated in Figures 4.8-4 to 4.8-8. Figure 4.8-5 shows concepts having single curvature (3S), while Figure 4.8-6 shows a compound curvature concept (3C). The aluminum alloy selected was 2024 aluminum. Skins and brake-formed discrete parts were in the T-3 condition. The parts formed on the rubber press were in the "O" or "W" condition and solution heat treated to a final condition of T-42. The brake-formed parts were straight channels and Z-sections. Curved channels and Z-sections were formed on the rubber press. All skins were Farnham rolled. Further ground rules and manufacturing assumptions are as follows:

- 3.5t bend radii
- Zee frames used
- Channel stringers used
- Frames joggled at stringers
- Clips used at frame/stringer joints
- Sealant used on faying surface and fasteners
- Rivets installed automatically (80% automatically and 20% manually).

The design/analysis assumptions were:

- Shear buckling permitted
- No inter-fastener buckling
- No frame or stringer buckling
- No crippling of stringers in compression.

The strength and weight of each concept were determined using conventional methods of stress analysis. The MC/DG was utilized to complement the design process by determining the manufacturing cost of each concept.

The optional cost worksheet was used, along with the supporting data sheet, to calculate the cost of the panels for the program. Worksheets are shown in Tables 4.8-1 and 4.8-2 for concepts 4 and 5. Examples of the data obtained from the MC/DG formats were noted on the worksheet in the appropriate columns. The formats utilized to determine the manufacturing man-hours are shown in Figures 4.8-9 to 4.8-12 and the dashed lines indicate how the measurements and fastener count are used to read the man-hours.

Examples of how the data from the formats were used for concepts 4 and 5 are shown following the summary for the trade-off. It is interesting to note that the cost for both concepts 4 and 5 is the same. This is because facility limitations constrained the contoured parts to be formed using the rubber press method, instead of the less expensive brake and roll method. The only difference between the two concepts is the addition of lightening holes to the frames in concept 5. In the rubber press operations, the provision of lightening holes does not require any additional operations.

Table 4.8-3 provides the results for the cost, weight, and cost-per-pound of the single curvature concepts. The compound curvature concept (No. 3C) was similar to one of the single curvature concepts (No. 3S), and, as expected, the MC/DG showed the compound curvature concept to be more expensive (Table 4.8-4). Table 4.8-5 summarized the cost-weight trade-offs for the concepts and also shows the cost of weight saved in dollars-per-pound. These data will allow the design team to select the cost-optimized fuselage shear panel that will also satisfy other program parameters.

The results of this integrated example reflect the MC/DG User's Guide as an effective aid to the design engineer. It allows easy qualitative cost guidance and also quantitative manufacturing cost trade results. Furthermore, it is sensitive to configuration variations.

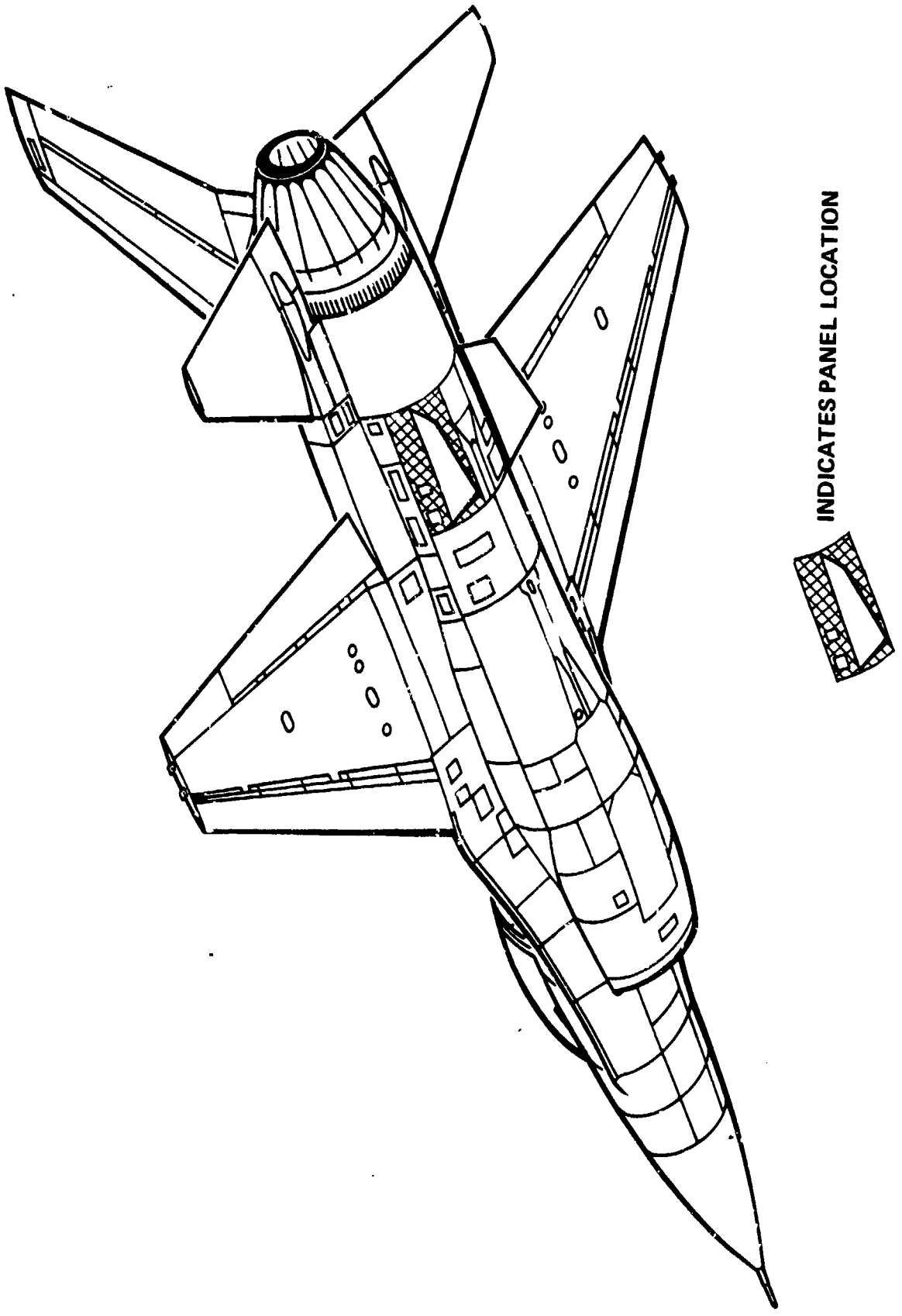
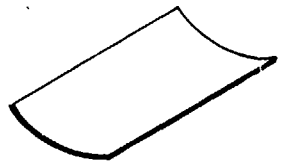
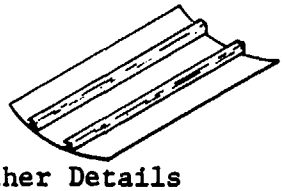



FIGURE 4.8-2. LOCATION OF ALUMINUM CONCEPTUAL PANEL ON F-16 FUSELAGE

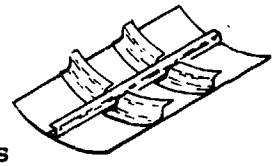
## SINGLE CURVATURE PANELS

| CONCEPT NO. | DESCRIPTION |
|---|---|
| 1 | UNSTIFFENED SKIN |
| 2 | 2 STRINGERS |
| 3S | 1 STRINGER, 2 FRAMES |
| 4 | 3 FRAMES |
| 5 | 3 FRAMES WITH CUTOUTS |

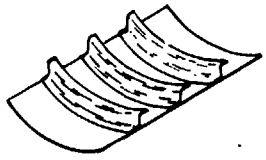




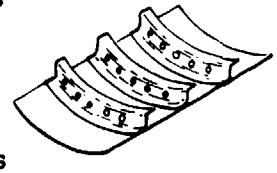
See Figure 4.8-4 for Further Details



See Figure 4.8-5 for Further Details



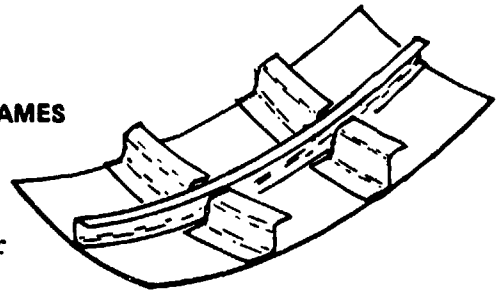
See Figure 4.8-7 for Further Details



See Figure 4.8-8 for Further Details

## COMPOUND CURVATURE, TAPERED WIDTH PANEL

| CONCEPT NO. | DESCRIPTION |
|---|---|
| 3C | 1 STRINGER, 2 FRAMES |



See Figure 4.8-6 for Further Details

FIGURE 4.8-3. CONCEPTS EVALUATED IN ALUMINUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

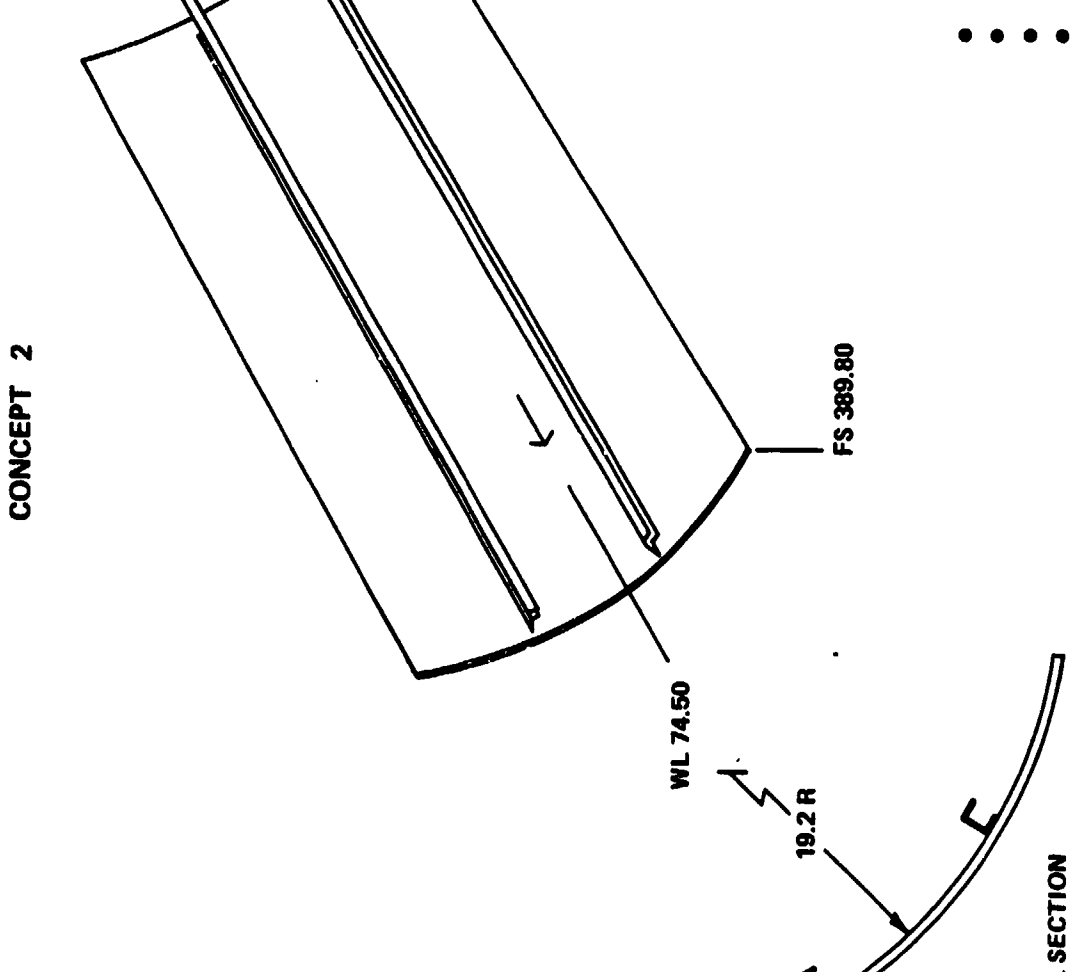
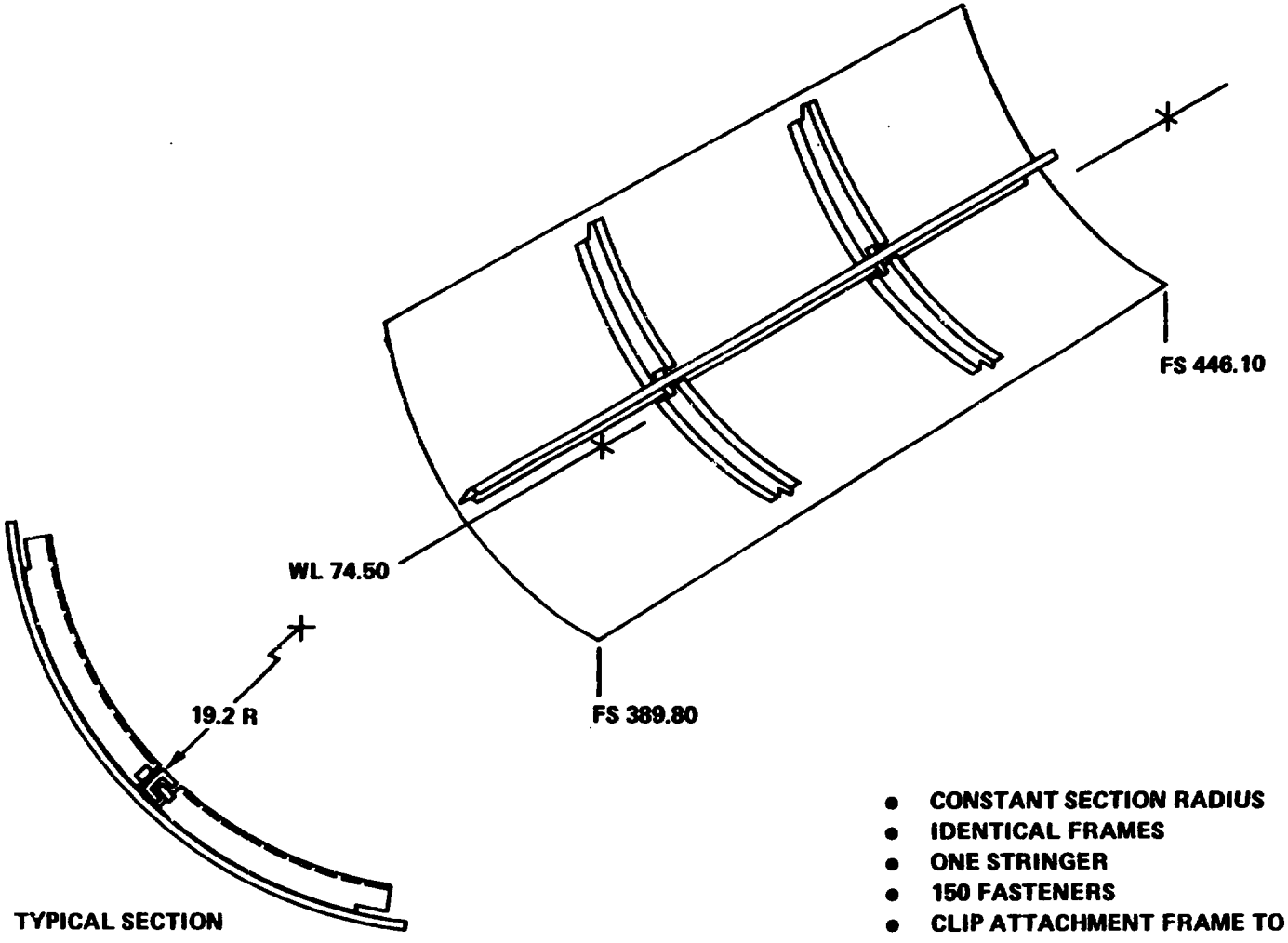



FIGURE 4.8-4. F-16 SIMPLIFED ENGINE ACCESS COVER (16B6530)

## CONCEPT 3S




- CONSTANT SECTION RADIUS
- IDENTICAL FRAMES
- ONE STRINGER
- 150 FASTENERS
- CLIP ATTACHMENT FRAME TO STRINGER

FIGURE 4.8-5. F-16 SIMPLIFED ENGINE ACCESS COVER (16B6530)

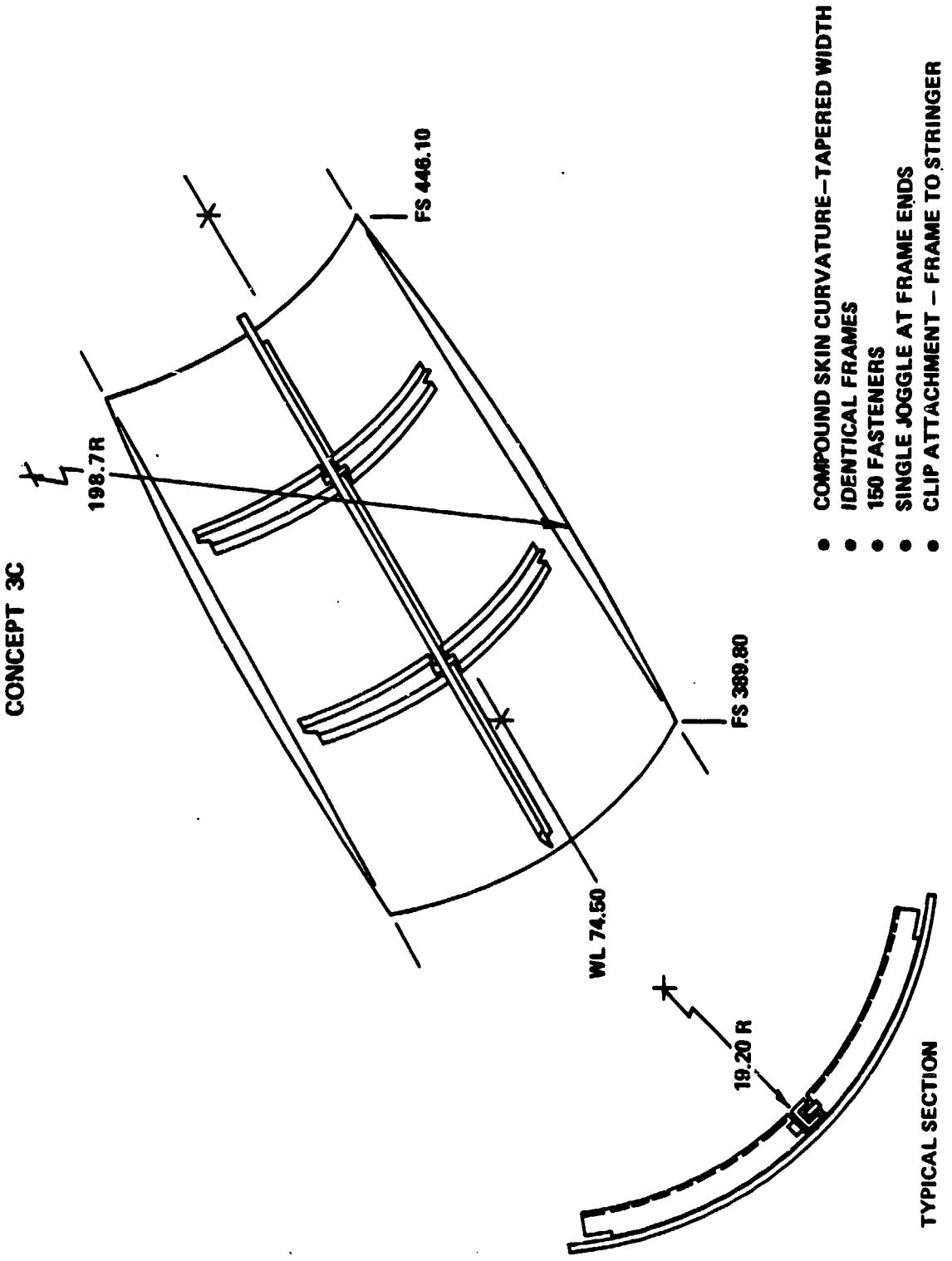
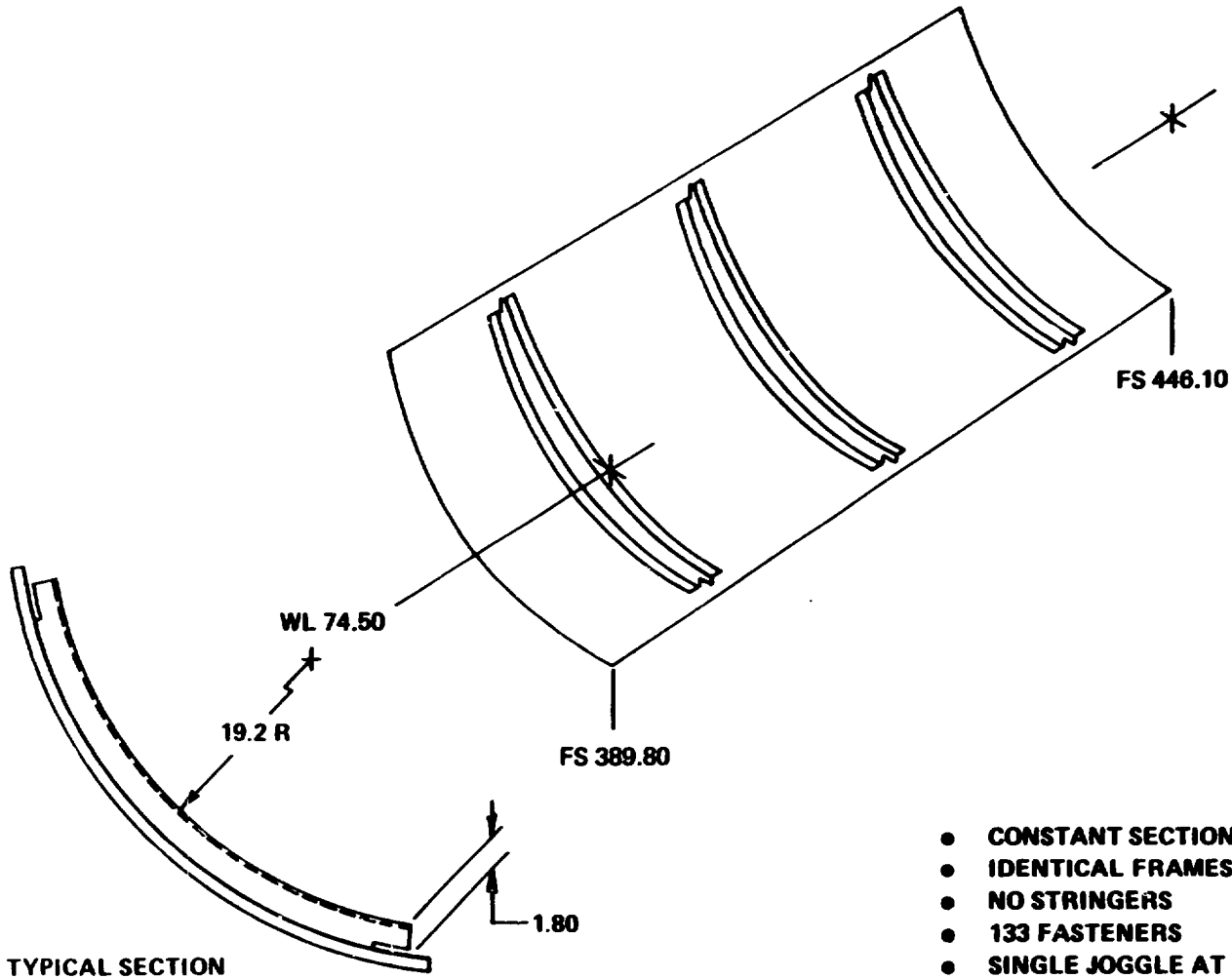


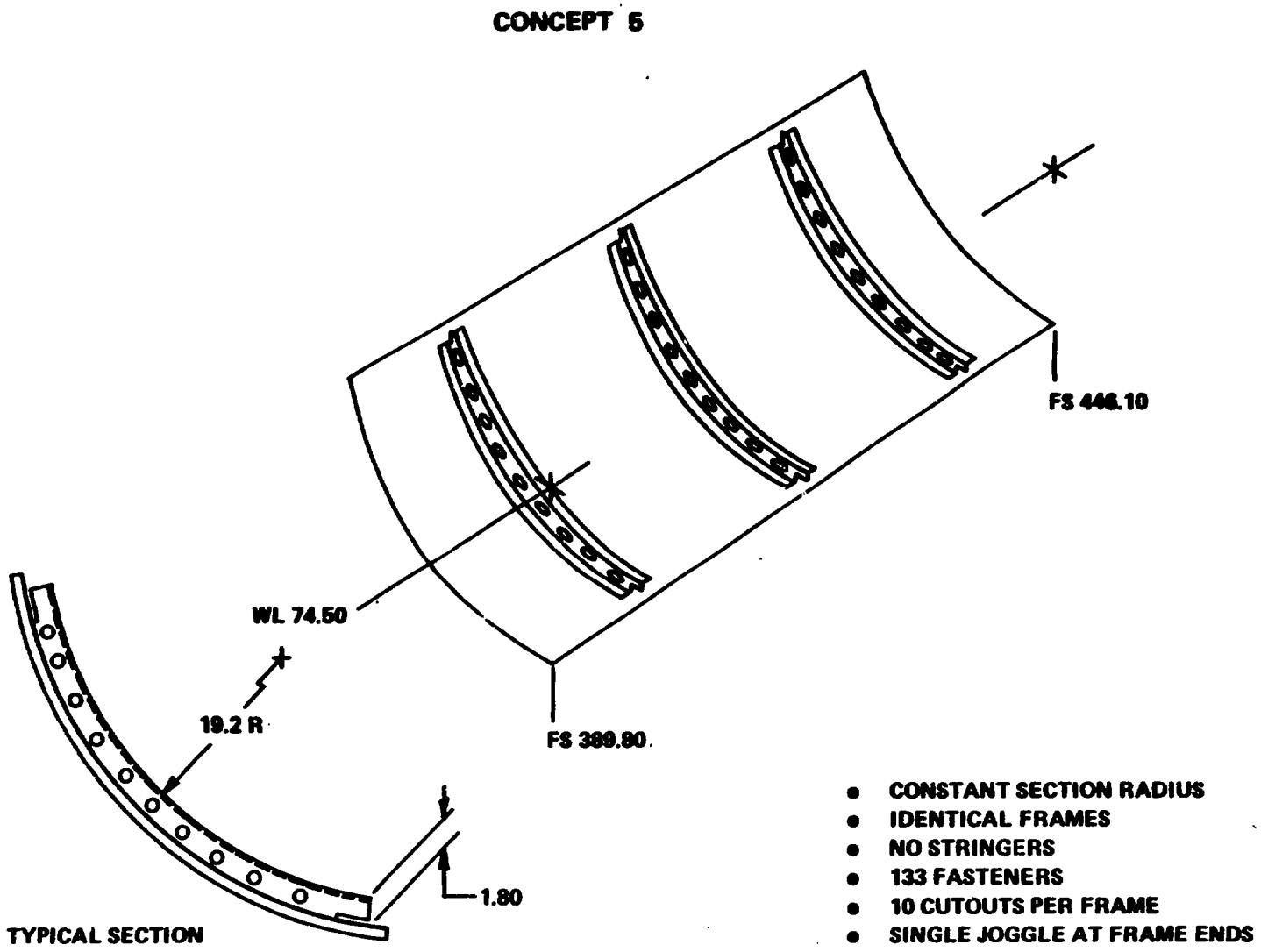

FIGURE 4.8-6. F-16 SIMPLIFED ENGINE ACCES. COVER (16B6530)

CONCEPT 4




- CONSTANT SECTION RADIUS
- IDENTICAL FRAMES
- NO STRINGERS
- 133 FASTENERS
- SINGLE JOGGLE AT FRAME ENDS

FIGURE 4.8-7. F-16 SIMPLIFED ENGINE ACCESS COVER (16B6530)




- CONSTANT SECTION RADIUS
- IDENTICAL FRAMES
- NO STRINGERS
- 133 FASTENERS
- 10 CUTOUTS PER FRAME
- SINGLE JOGGLE AT FRAME ENDS

FIGURE 4.8-8. F-16 SIMPLIFIED ENGINE ACCESS COVER (16B6530)

TABLE 4.8-1. MC/DG COST WORKSHEET

CONCEPT NO. IA: 3 FRAMES(4)
CONCEPT NO. IB: 3 FRAMES WITH CUTOUTS(5)

PAGE 1 of 2

| DESIGN CONCEPT | | RECURRING COST (RC) | | | | | | | | | NON-RECURRING COST (NRC) | | | PROGRAM COST | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L . LC . LR = LB + MB = RC . P/AC . DG = PRC | | | | | | | | | NRC . LR = PNRC | | | 9 + 12 ÷ DG = COST/AC | | |
| PART NO. | DESCRIPTION | LABOR MC/DG MAN/PT (1) | LC FACTOR (2) | LABOR RATE $/MAN (3) | LABOR RC $/PT (4) | MAT'L $/PT (5) | RBC. COST/ PT. $ (6) | PARTS PER AC (7) | DES. QTY. (8) | PROD. RC $ (9) | NRC MC/DG MAN (10) | LABOR RATE $/MAN (11) | PROD. NRC $ (12) | PROD. COST $ (13) | DES. QTY. (14) | COST/ AC $ (15) |
| 1 | SKIN | 1.08 | 1.00 | 25 | 27.00 | 21.93 | 48.93 | 1 | 200 | 9786 | 68 | 25 | 1700 | | | |
| 2 | FRAMES | 0.498 | 1.00 | 25 | 12.45 | 0.91 | 13.36 | 3 | 200 | 8016 | 84 | 25 | 2100 | | | |
| | | | | | | | | | | | | | | | | |
| | ASSEMBLY | 3.0 | 1.00 | 25 | 75.00 | 33.25 | 108.25 | 1 | 200 | 21650 | 462 | 25 | 11550 | | | |
| | TOTALS | | | | | | | | | 39452 | | | 15350 | 54802 | 200 | 274 |

BY: B. R. Moton

DATE: FEB '82

TABLE 4.8-2. COST WORKSHEET — SUPPORTING DATA

CONCEPT NO. IA:
CONCEPT NO. IB:

PAGE 2 OF 2

| | |
|---|---|
| PART: SKIN → T3 CONDITION<br>BASE PART - CED-A-20 - 1.03 MH/PART TOOL - 68 MH<br><br>MATERIAL: 14.15 SQ.FT. @ $1.55/SQ.FT. $21.93 | PART: |
| PART: FRAME - ZEE (RUBBER PRESS)<br>BASE PART - CED-A-9 0.498 MH/PART TOOL 84 MH<br><br>MATERIAL: 0.91 SQ.FT. @ $1.00/SQ.FT. = $0.91/PART | PART: |
| PART: | PART: |
| ASSEMBLY: CED-MFA-1 and CED-MFA-3<br>133 RIVETS 3 MH/ASSEMBLY TOOL 462<br>15.38 FT OF PERIMETER<br><br>MATERIAL: 133 RIVETS @ $0.25/RIVET = $33.25/ASSEMBLY | ASSEMBLY: |

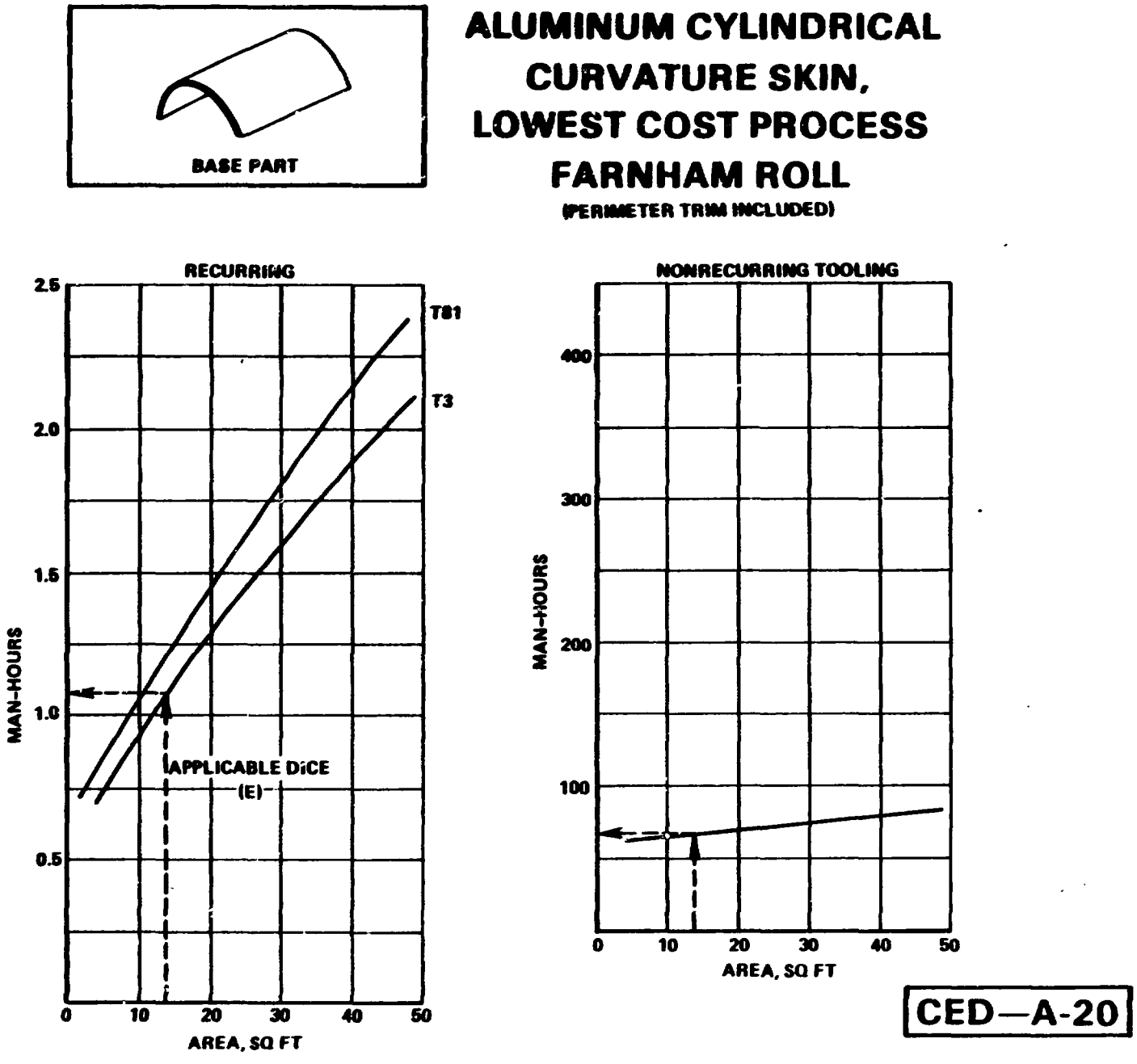


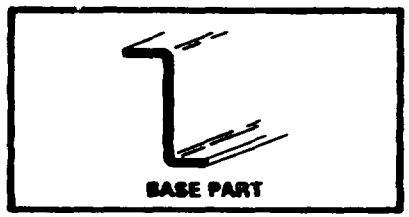

FIGURE 4.8-9. FORMAT USED IN TRADE-OFF STUDY

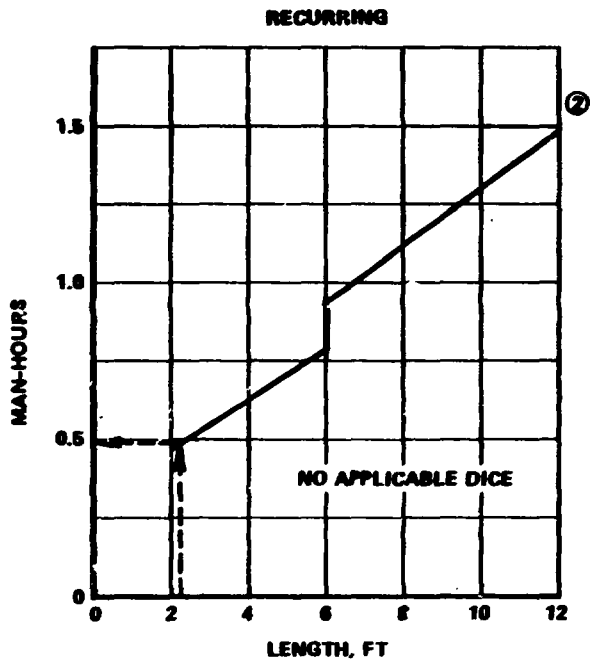


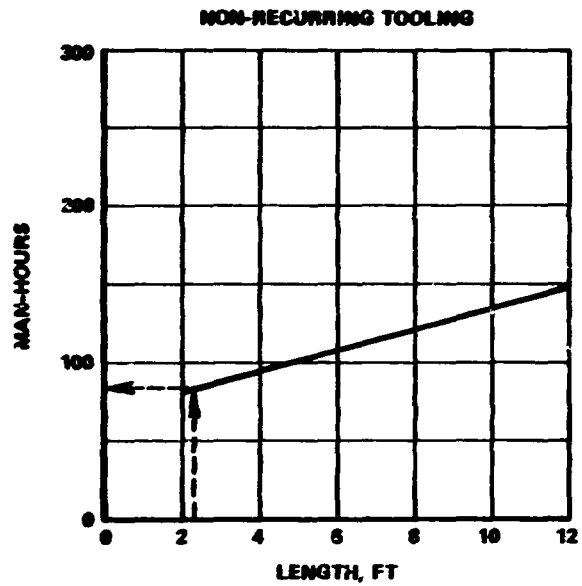
FTR450261000U
3 Jan 1983

# ALUMINUM ZEE, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

## RUBBER PRESS




*NO REVERSE CURVES
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

CED—A-9

FIGURE 4.8-10. FORMAT USED IN TRADE-OFF STUDY

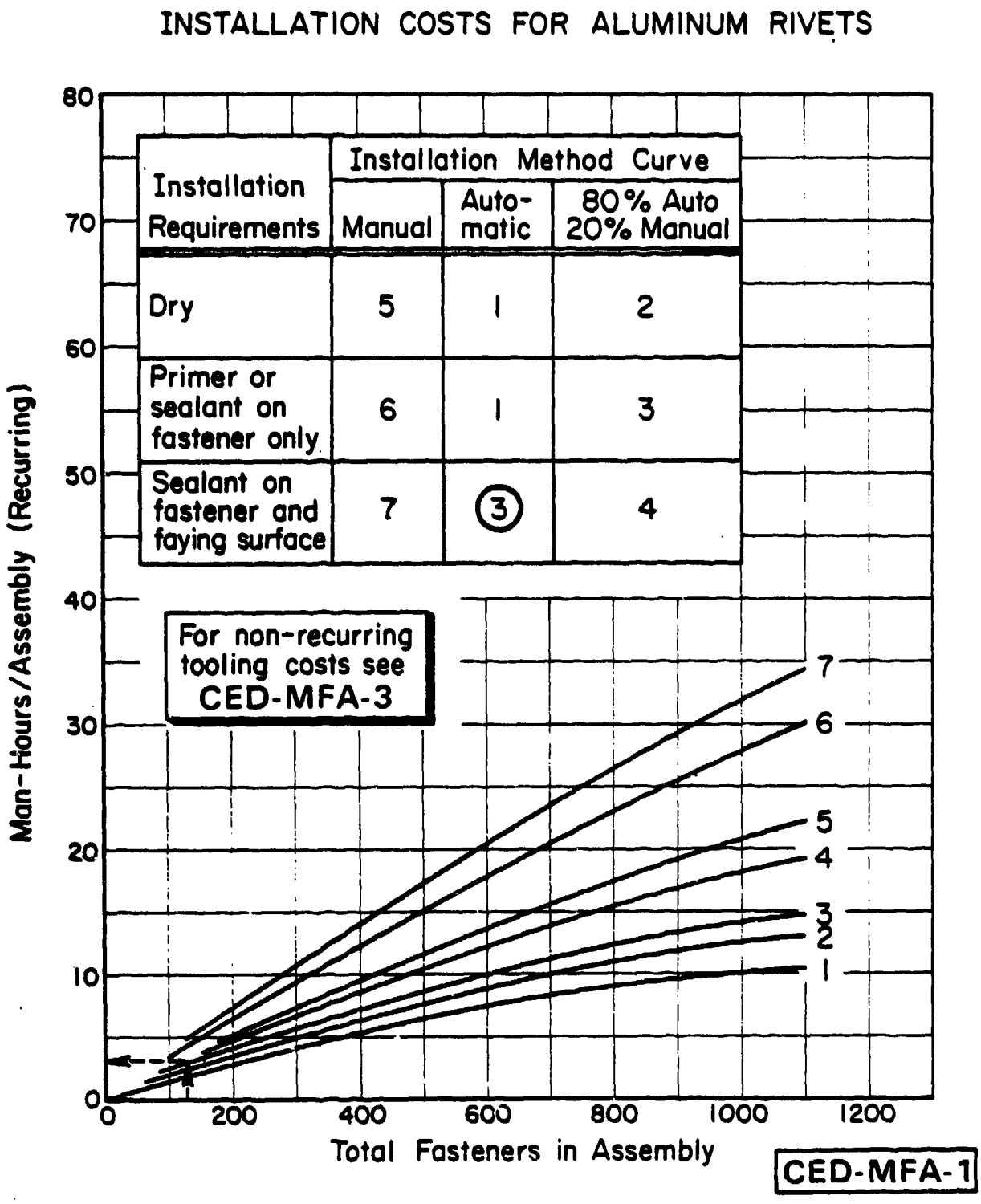



FIGURE 4.8-11. FORMAT USED IN TRADE-OFF STUDY

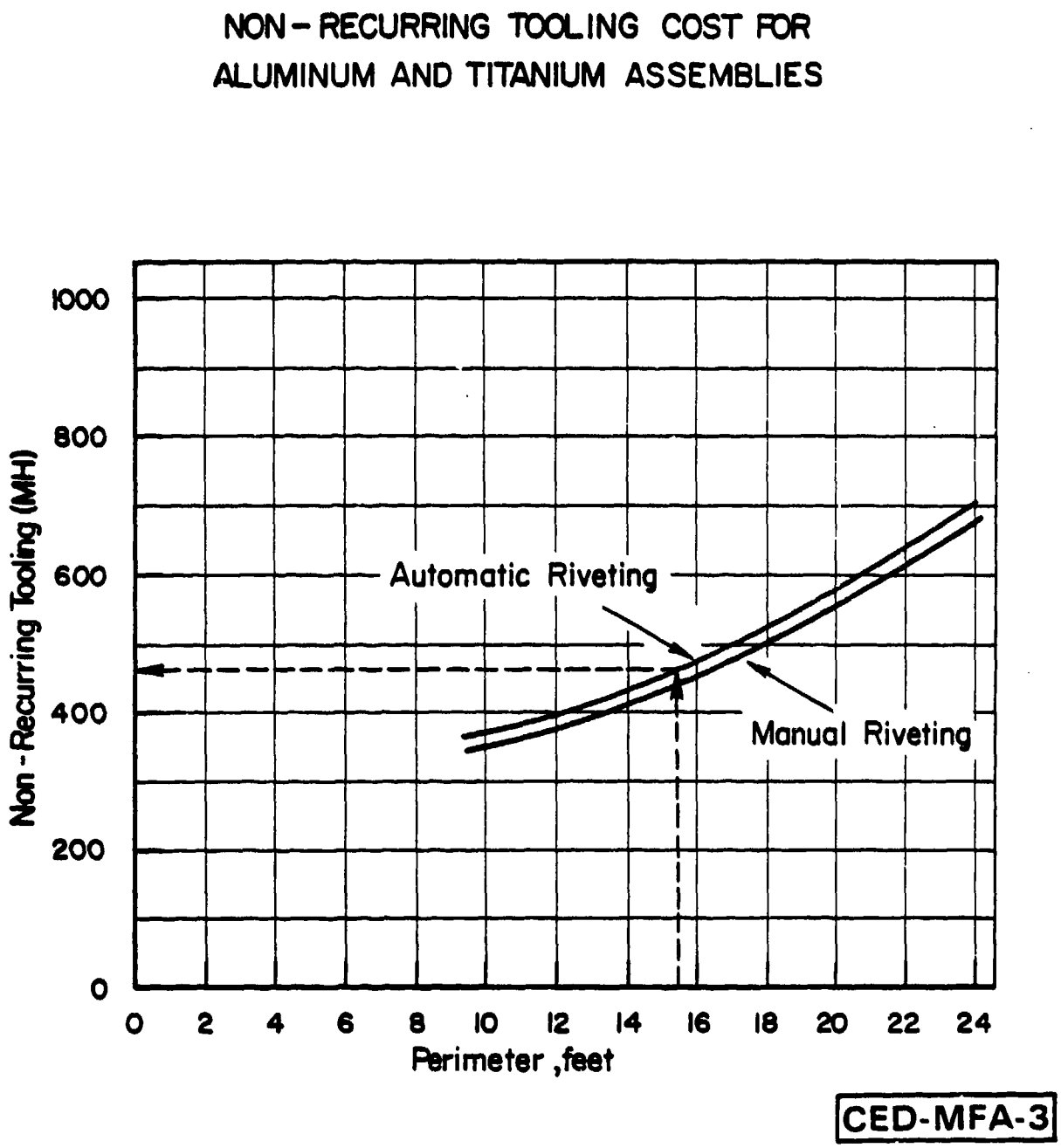
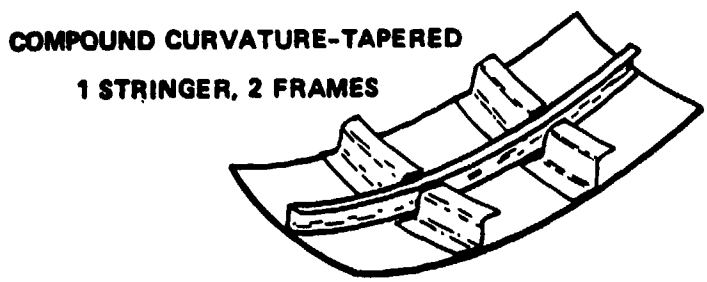



FIGURE 4.8-12. FORMAT USED IN TRADE-OFF STUDY

TABLE 4.8-3. SUMMARY OF COST-WEIGHT RELATIONSHIPS IN ALUMINUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

| CONCEPT | | COST, $ | WEIGHT, LBS | COST PER LB, $/LB |
|---|---|---|---|---|
| 1 | UNSTIFFENED | 63 | 21.22 | 3 |
| 2 | 2 STRINGERS | 246 | 19.68 | 13 |
| 3S | 2 FRAMES 1 STRINGER | 309 | 19.83 | 16 |
| 4 | 3 FRAMES | 274 | 19.06 | 14 |
| 5 | 3 FRAMES (WITH CUTOUTS) | 274 | 19.03 | 14 |

TABLE 4.8-4. INFLUENCE OF CURVATURE ON COST AND WEIGHT




| CONCEPT | | COST, $ | WEIGHT, LB | COST PER LB WEIGHT, $/LB |
|---|---|---|---|---|
| 3S | SINGLE CURVATURE | 309 | 19.83 | 16 |
| 3C | COMPOUND CURVATURE | 352 | 18.98 | 19 |

TABLE 4.8-5. SUMMARY OF RESULTS IN ALUMINUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

| CONCEPT | | COST | | WEIGHT | | COST OF WEIGHT SAVED, $/LB |
|---|---|---|---|---|---|---|
| | | $/PART | Δ$/PART | LBS/PART | ΔLBS/PART | |
| 1 | UNSTIFFENED | 63 | BASE | 21.22 | BASE | BASE |
| 2 | 2 STRINGERS | 246 | 183 | 19.68 | 1.54 | 119 |
| 3S | 2 FRAMES 1 STRINGER | 309 | 246 | 19.83 | 1.39 | 177 |
| 4 | 3 FRAMES | 274 | 211 | 19.06 | 2.16 | 98 |
| 5 | 3 FRAMES (WITH CUTOUTS) | 274 | 211 | 19.03 | 2.19 | 96 |

### 4.8.3 Titanium Fuselage Panel

To illustrate the procedure of using manufacturing data from various sections of the MC/DG, details of a trade-off conducted on a series of concepts for a titanium shear fuselage panel are presented here. Figure 4.8-13 shows the panel selected. The approach used for this trade-off is shown in Figure 4.8-14.

The study commenced with a review of the MC/DG ground rules and also of the structural sections available in the MC/DG which are shown in Figure 4.8-15. The second step was to specify the structural design premises and the characteristics of the panel designs. The dimensions selected for the panel were 36 x 72 inches with a uniform curvature of 60-inch radius. The applied loads and structural design criteria are summarized in Figure 4.8-16. These criteria were retrieved from studies earlier conducted at Lockheed-California Company on the first and second generation SST but modified to reflect the prescribed ground rules of the Section 4.1 for Sheet Metal.

The third step in conducting the trade-off was to develop the candidate design configurations. Table 4.8-6 provides a summary of the seven design concepts (I-VII) considered and also indicates the structural member spacings, A and B (shown in Figure 4.8-13) for each concept. The concept variables were the number of frames, number and type of stringers, and skin thickness. Figures 4.8-17 through 4.8-23 are the drawings of each concept (I-VII), which include a list of parts. Table 4.8-7 summarizes the concepts and provides the number, type, dimensions of each part and also the number of rivets (fastener count) required for assembly.

The final step of the trade-off, was to estimate the cost and weight of each concept. Standard weight estimation procedures were used. The total cost of each concept was determined using the MC/DG Designer's Worksheet and an example of its utilization for Concept I is shown in Table 4.8-8. Supporting data for entry on this worksheet are shown in Table 4.8-9. Instructions for completing the MC/DG Designer's Worksheet are provided in Table 4.8-10. In column 2 of Table 4.8-8, the learning curve factor is specified. Typical values for industry learning curves are shown in Table 4.8-11, where the manufacturing operations required for the titanium shear panel are indicated. The factors to convert the MC/DG 200th unit cost for the design quantity and learning curve involved are provided in Table 4.8-11. For a design quantity of 200 aircraft (Table 4.8-8) and learning curves of 75%, 85%, and 90%, the factors are 1.17, 1.30, and 1.66, respectively.

Examples of formats that were used in the MC/DG to conduct the trade-offs are shown in Figures 4.8-24 to 4.8-31. Dashed lines and arrows included on these formats indicate how the manufacturing cost data were retrieved.

With both the manufacturing cost and weight of each panel determined for each candidate design, the data can be organized by the designer into a convenient form for subsequent selection of the optimum panel design. Table 4.9-12 summarizes the cost and weight of each concept. In this summary, the least costly panel, Concept VII, was selected as the baseline design. The weight and cost increments for each panel can now be calculated relative to the baseline design. The increments are utilized to determine the cost of weight saved (dollars per pound). These results are also included in Table 4.8-12. The designer concluded from these data that Concept II is the recommended panel design. In order to confirm this decision, Table 4.8-13 was prepared with Concept II as the baseline design. The increments and cost of weight saved were again calculated. The results shown in Table 4.8-13 indicate that Concept II was the correct choice.

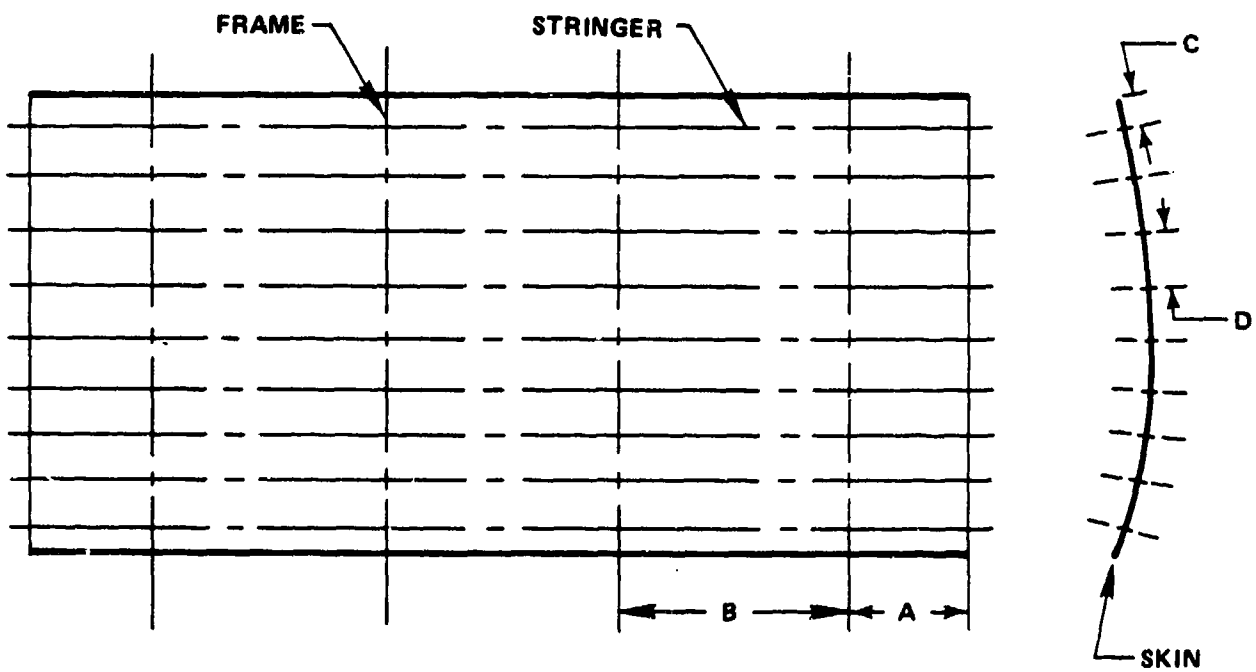



FIGURE 4.8-13. TITANIUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

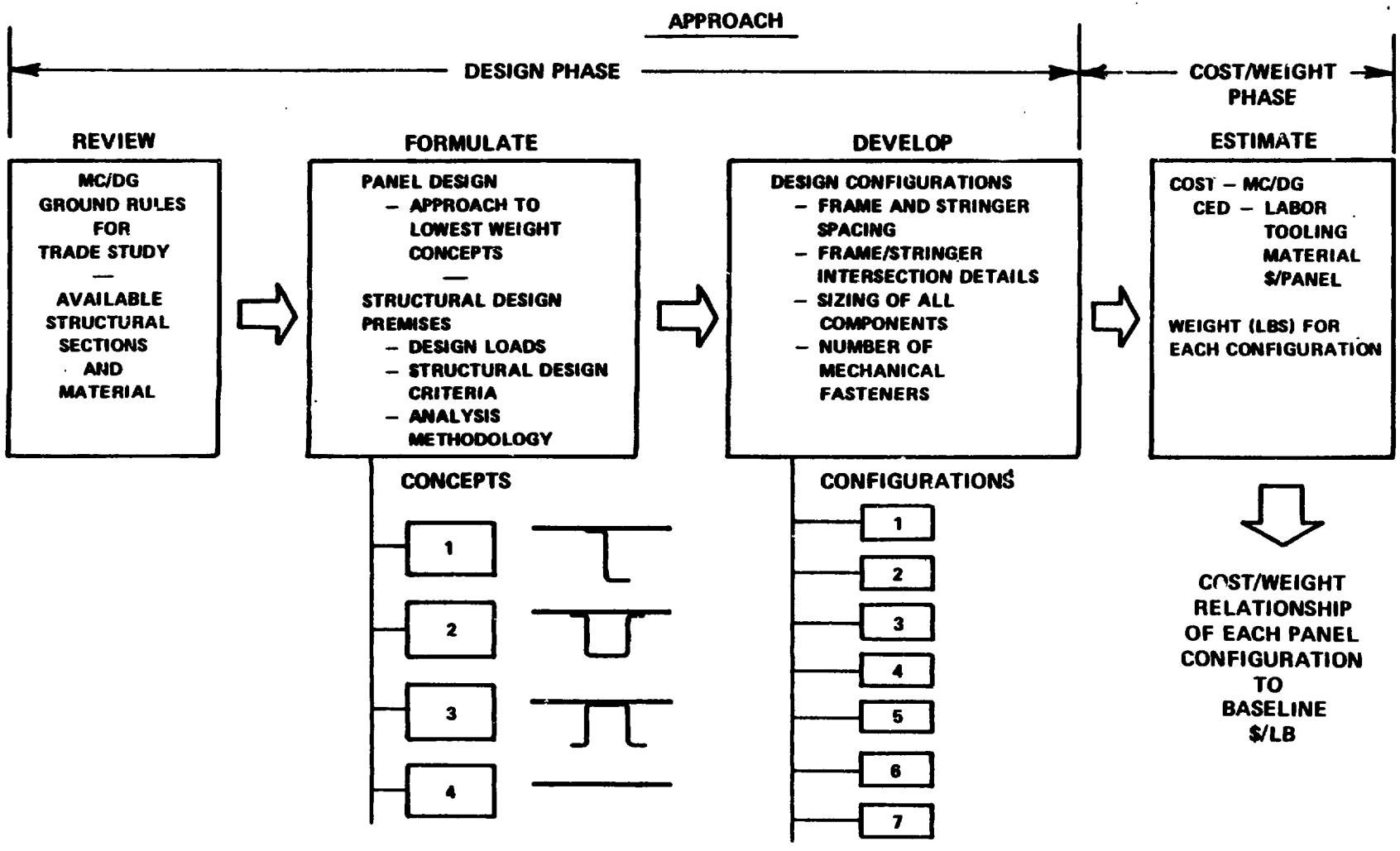
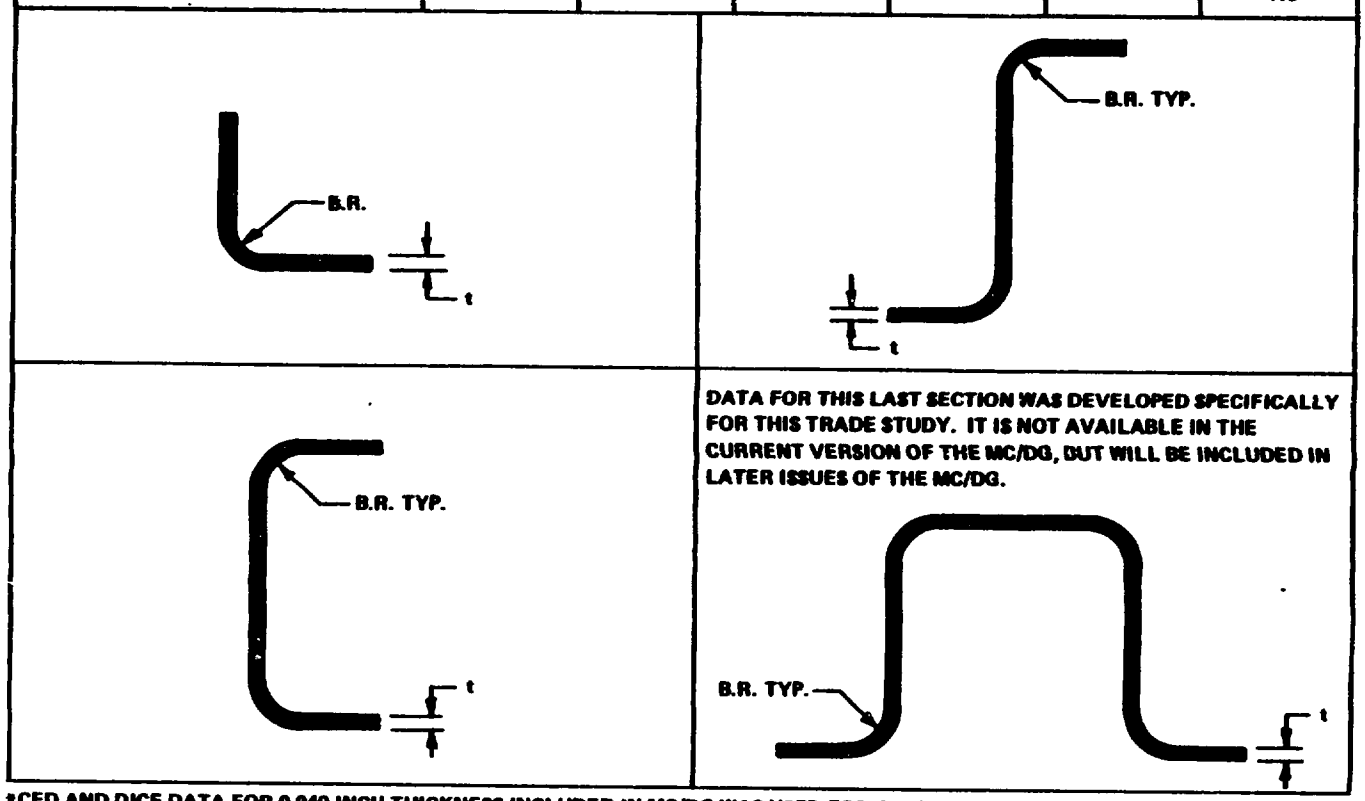


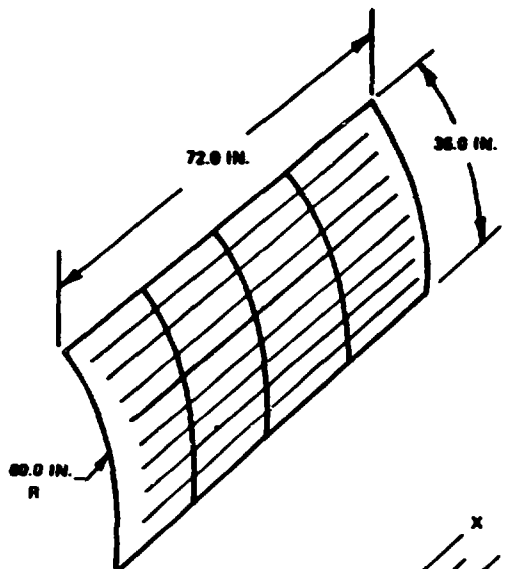

FIGURE 4.8-14. TITANIUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY PHASES

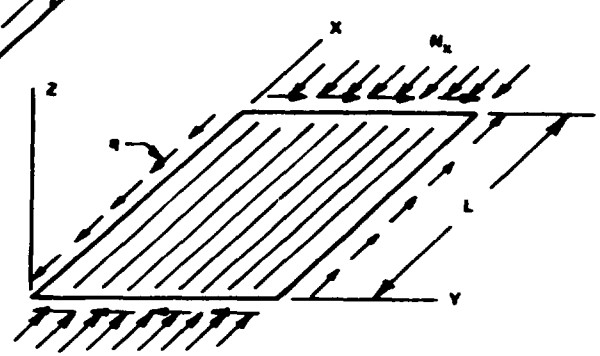
| ITEM | THICKNESS–INCHES* | | | | | |
|---|---|---|---|---|---|---|
| | .025 | .030 | .040 | .050 | .062 | .080 |
| 5t BEND RADIUS – RT | .12 | .16 | .22 | .25 | .31 | .44 |
| 2t BEND RADIUS – HOT | .06 | .06 | .09 | .12 | .12 | .16 |




*CED AND DICE DATA FOR 0.040 INCH THICKNESS INCLUDED IN MC/DG WAS USED FOR OTHER THICKNESSES SHOWN IN THIS TRADE STUDY, WHICH ARE NOT AVAILABLE IN THE CURRENT MC/DG.

FIGURE 4.8-15. AVAILABLE MC/DG TITANIUM STRUCTURAL SECTIONS




PANEL ORIENTATION AND STRESS RESULTANTS

STRUCTURAL DESIGN PREMISES
- DESIGN LOADS
  - 1ST AND 2ND GENERATION SST STUDIES

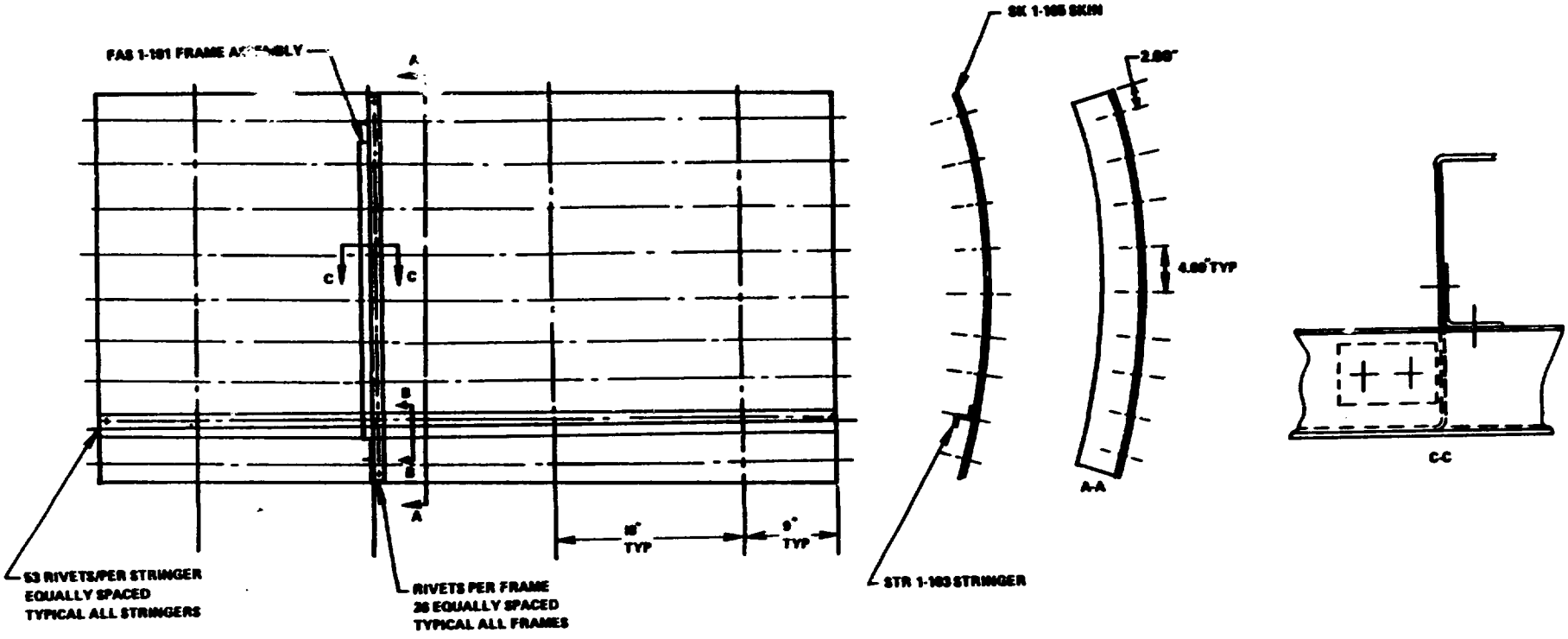
| STRESS RESULTANTS | CONDITION 1 | CONDITION 2 |
|---|---|---|
| $N_x$ LB/IN. | 1500 | -1500 |
| q LB/IN. | 3000 | 3000 |

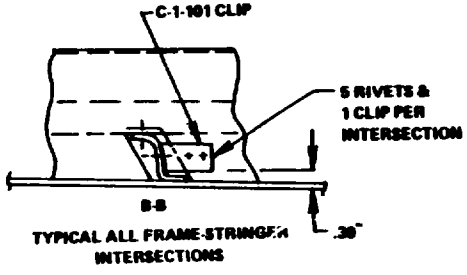
STRUCTURAL DESIGN CRITERIA
- DESIGN ALLOWABLES
  - MATERIAL PROPERTIES Ti 6Al-4V
    - MIL HDBK 5C
    - ROOM TEMPERATURE DESIGN PROPERTIES
  - STRUCTURAL GEOMETRY
  - REDUCED TENSION ALLOWABLES
    - FATIGUE AND FAIL SAFE
- SHEAR – SKIN
  - LOCAL & GENERAL INSTABILITY
  - FAILURE MODES – SHEAR BUCKLING
- COMPRESSION MEMBERS
  - LOCAL BUCKLING & CRIPPLING
- EXCLUDED FROM STRUCTURAL ANALYSIS
  - FATIGUE
  - FAIL SAFE
  - PRESSURIZATION
  - ACOUSTIC LOADING
  - LIGHTNING STRIKE
  - IMPACT PROTECTION
  - LIFE CYCLE COST
  - QUALITY ASSURANCE

FIGURE 4.8-16. TITANIUM FUSELAGE SHEAR-PANEL DIMENSIONS AND DESIGN PREMISES

TABLE 4.8-6. SUMMARY OF TITANIUM FUSELAGE SHEAR-PANEL CONCEPTS

| CONCEPT NO. | SKIN THICKNESS, IN. | NO. OF FRAMES | TYPE OF FRAME | NO. OF STRINGERS | TYPE OF STRINGERS | DIMENSIONS IN. | | DIMENSIONS, IN. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | B | C | D |
| I | 0.06 | 4 | ZEE | 9 | ZEE | 9.0 | 18.0 | 2.0 | 4.0 |
| II | 0.06 | 3 | ZEE | 9 | ZEE | 12.0 | 24.0 | 2.0 | 4.0 |
| III | 0.06 | 4 | ZEE | 8 | HAT (CLOSED) | 9.0 | 18.0 | 2.25 | 4.5 |
| IV | 0.06 | 3 | ZEE | 8 | HAT (CLOSED) | 12.0 | 24.0 | 2.25 | 4.5 |
| V | 0.075 | 4 | ZEE | 8 | HAT (OPEN) | 9.0 | 18.0 | 2.25 | 4.5 |
| VI | 0.075 | 3 | ZEE | 8 | HAT (OPEN) | 12.0 | 24.0 | 2.25 | 4.5 |
| VII | 0.190 | 9 | ZEE | 0 | – | 4.0 | 8.0 | – | – |

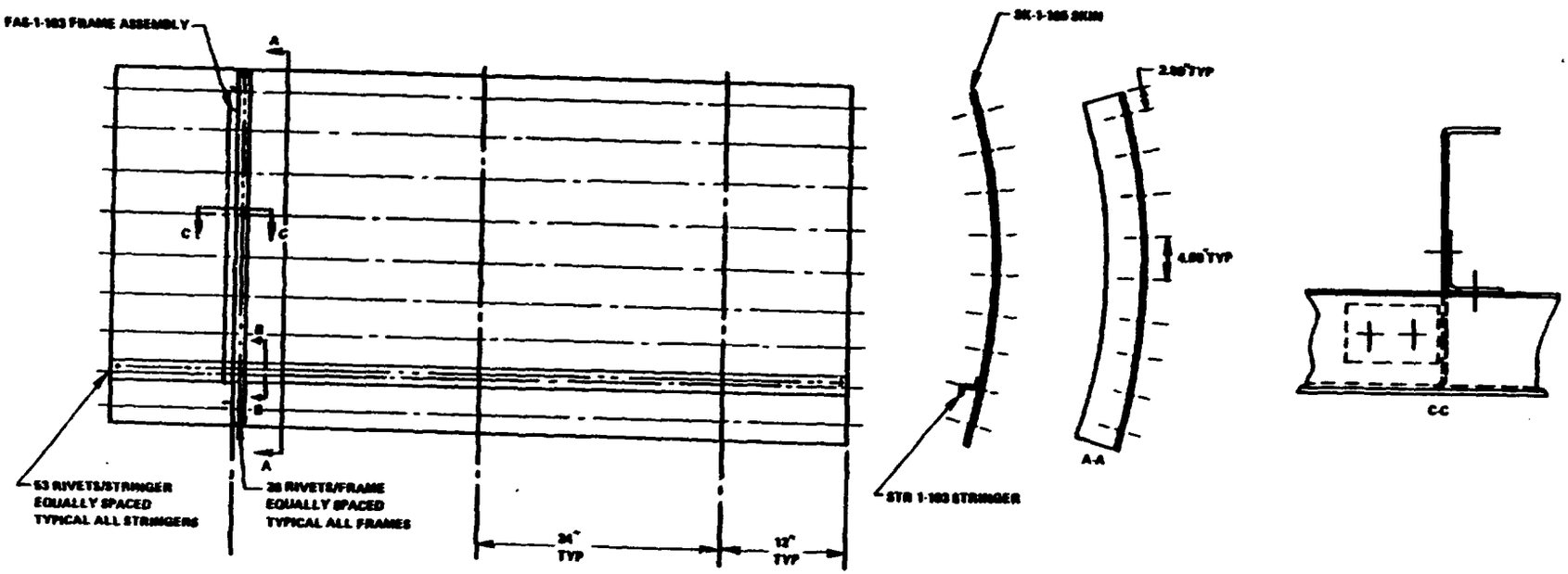


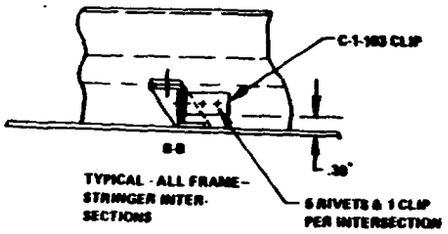




| ASSY. NO. | | DESCRIPTION | PART NO. |
|---|---|---|---|
| | | SKIN PANEL ASSY | -101 |
| | AR | RIVET - SIMETAL | |
| | 38 | CLIP | C-1-101 |
| | 9 | STRINGER - ZEE | STR 1-103 |
| | 4 | FRAME ASSY | FAS 1-101 |
| | 1 | SKIN | SK-1-105 |
| | -101 | | |

FUSELAGE PANEL ASSEMBLY
CONCEPT I

FIGURE 4.8-17. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. I

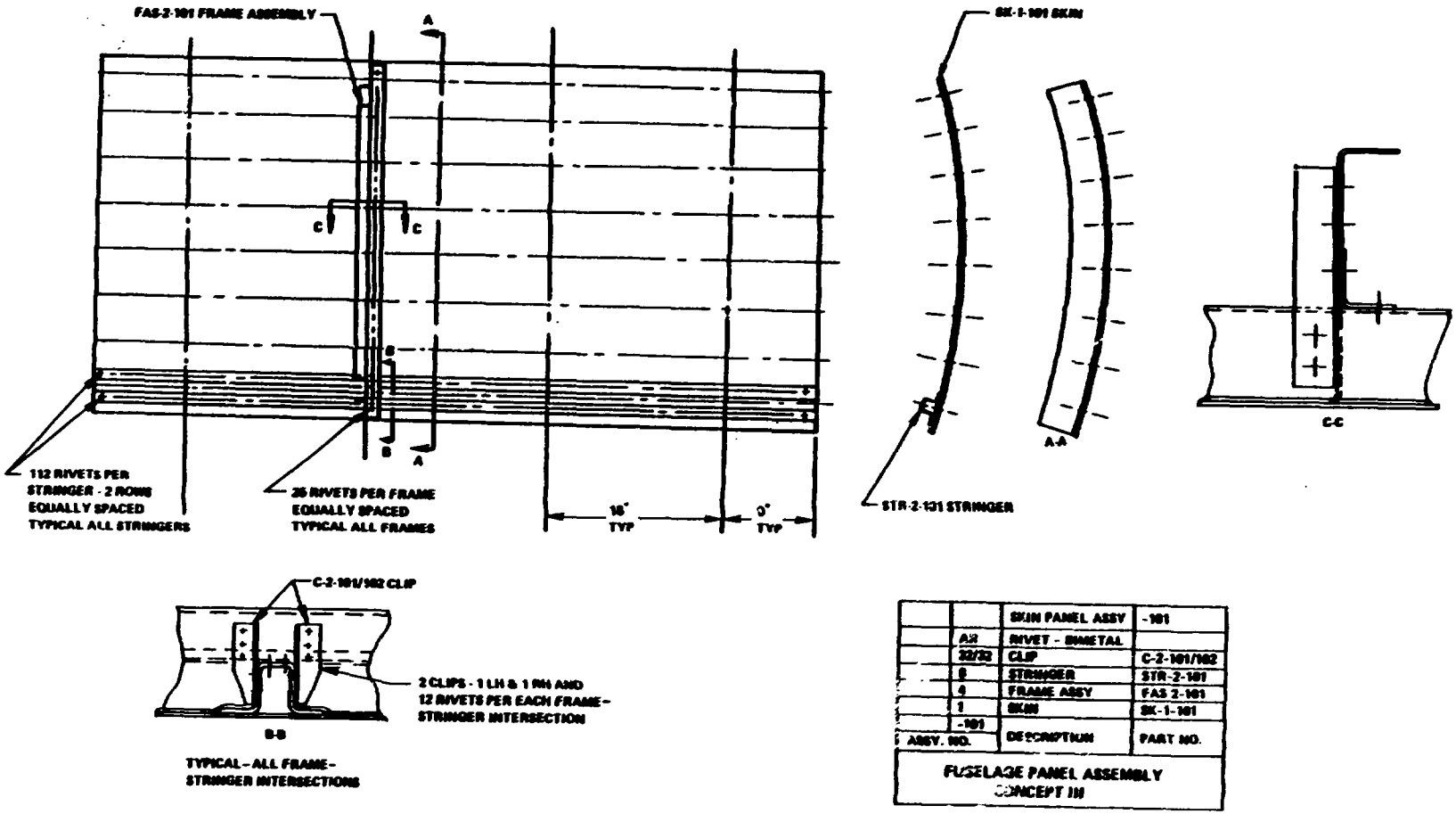



| ASSY. NO. | | DESCRIPTION | PART NO. |
|---|---|---|---|
| | | SKIN PANEL ASSY | -101 |
| | AR | RIVET - BIMETAL | |
| | 27 | CLIP | C-1-103 |
| | 9 | STRINGER - ZEE | STR 1-103 |
| | 3 | FRAME ASSY | FAS 1-103 |
| | 1 | SKIN | SK-1-105 |
| | -101 | | |

FUSELAGE PANEL ASSEMBLY
CONCEPT II

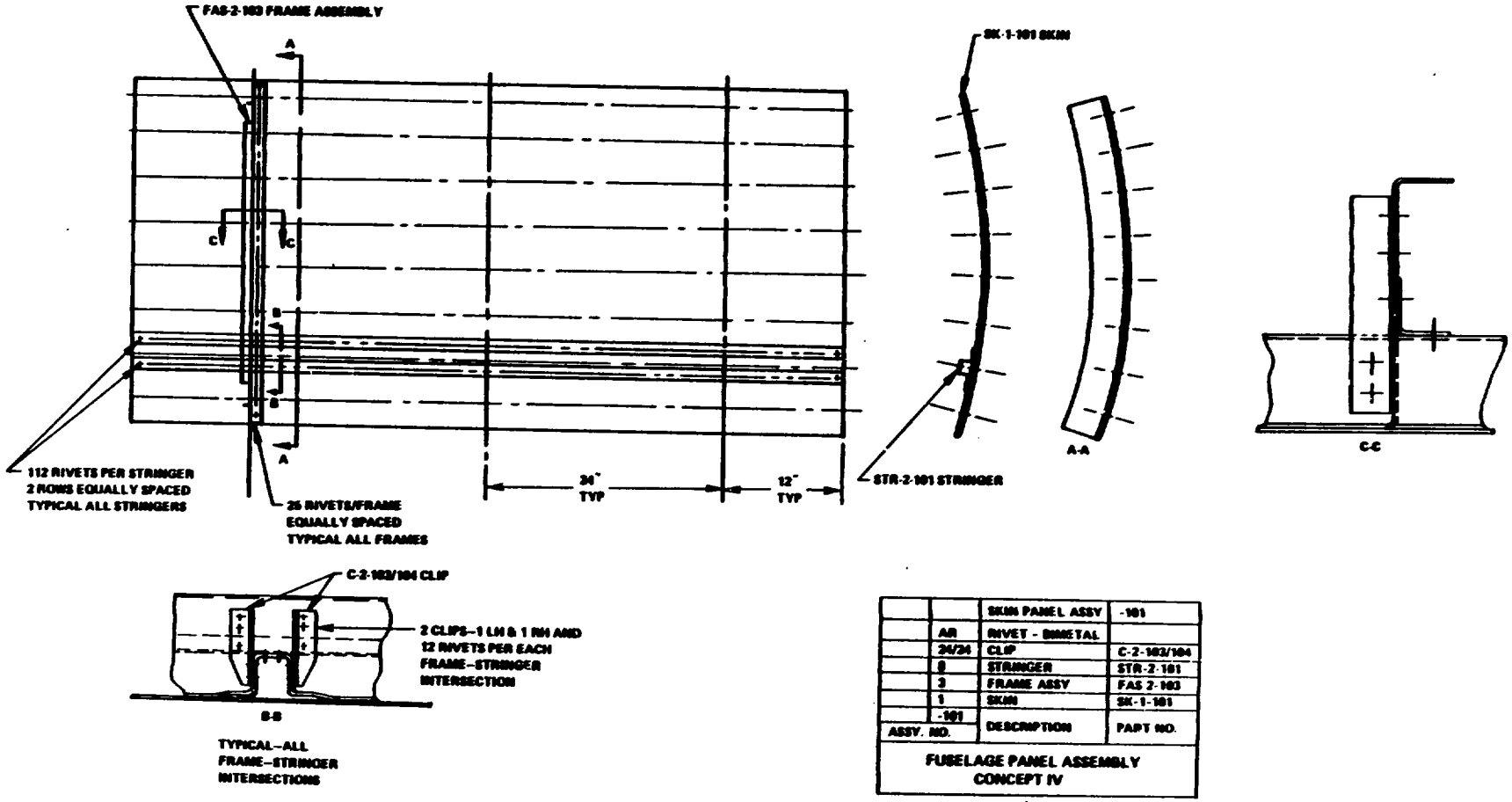
FIGURE 4.8-18. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. II




| ASSY. NO. | | DESCRIPTION | PART NO. |
|---|---|---|---|
| | | SKIN PANEL ASSY | -101 |
| | A/R | RIVET - BIMETAL | |
| | 32/32 | CLIP | C-2-101/102 |
| | 8 | STRINGER | STR-2-101 |
| | 4 | FRAME ASSY | FAS 2-101 |
| | 1 | SKIN | SK-1-101 |
| | -101 | | |

FUSELAGE PANEL ASSEMBLY
CONCEPT III

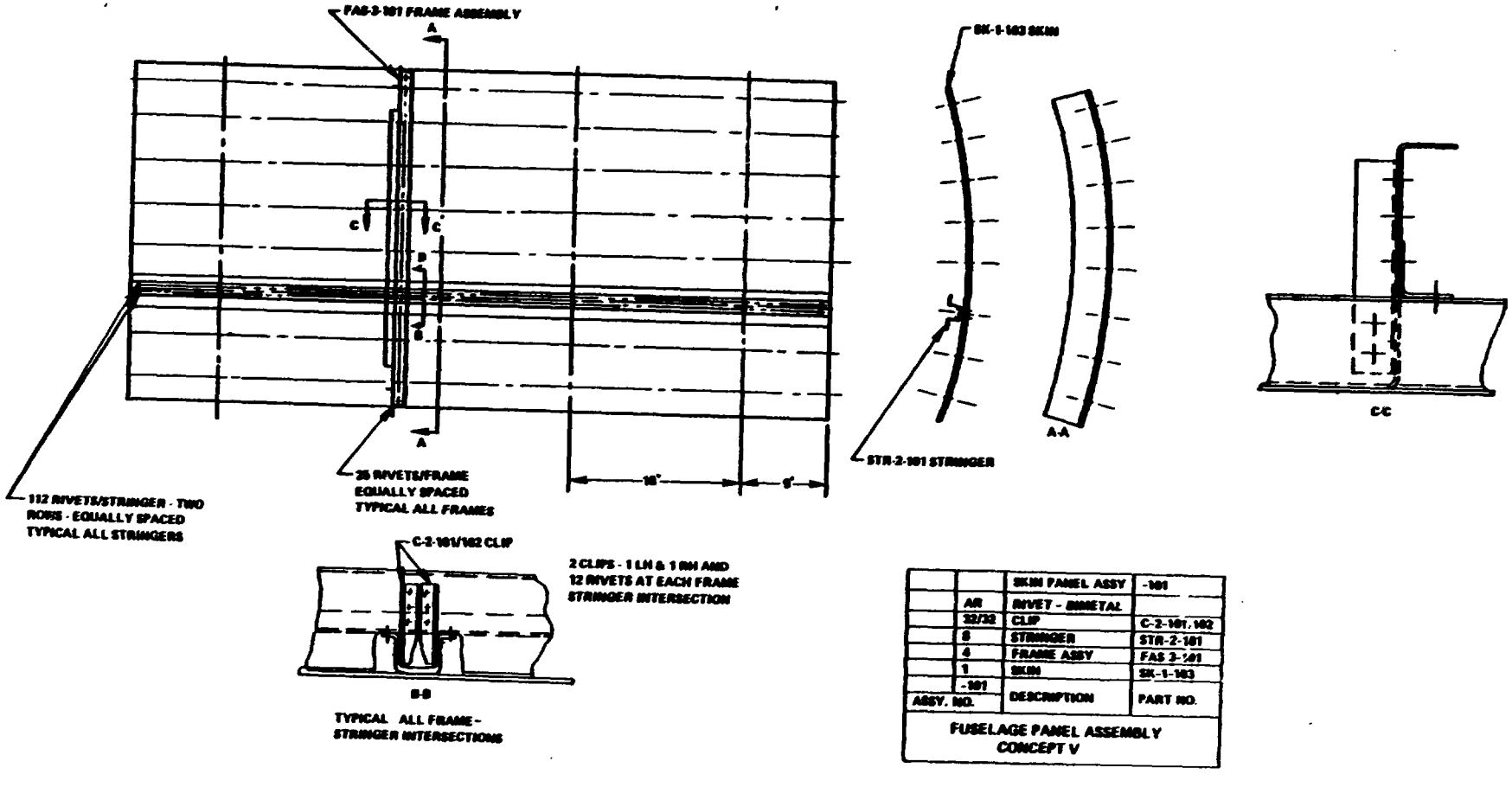
FIGURE 4.8-19. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. III




| ASSY. NO. | | DESCRIPTION | PART NO. |
|---|---|---|---|
| | | SKIN PANEL ASSY | -101 |
| | AR | RIVET - BIMETAL | |
| | 24/24 | CLIP | C-2-103/104 |
| | 8 | STRINGER | STR-2-101 |
| | 3 | FRAME ASSY | FAS 2-103 |
| | 1 | SKIN | SK-1-101 |
| | -101 | | |

FUSELAGE PANEL ASSEMBLY
CONCEPT IV

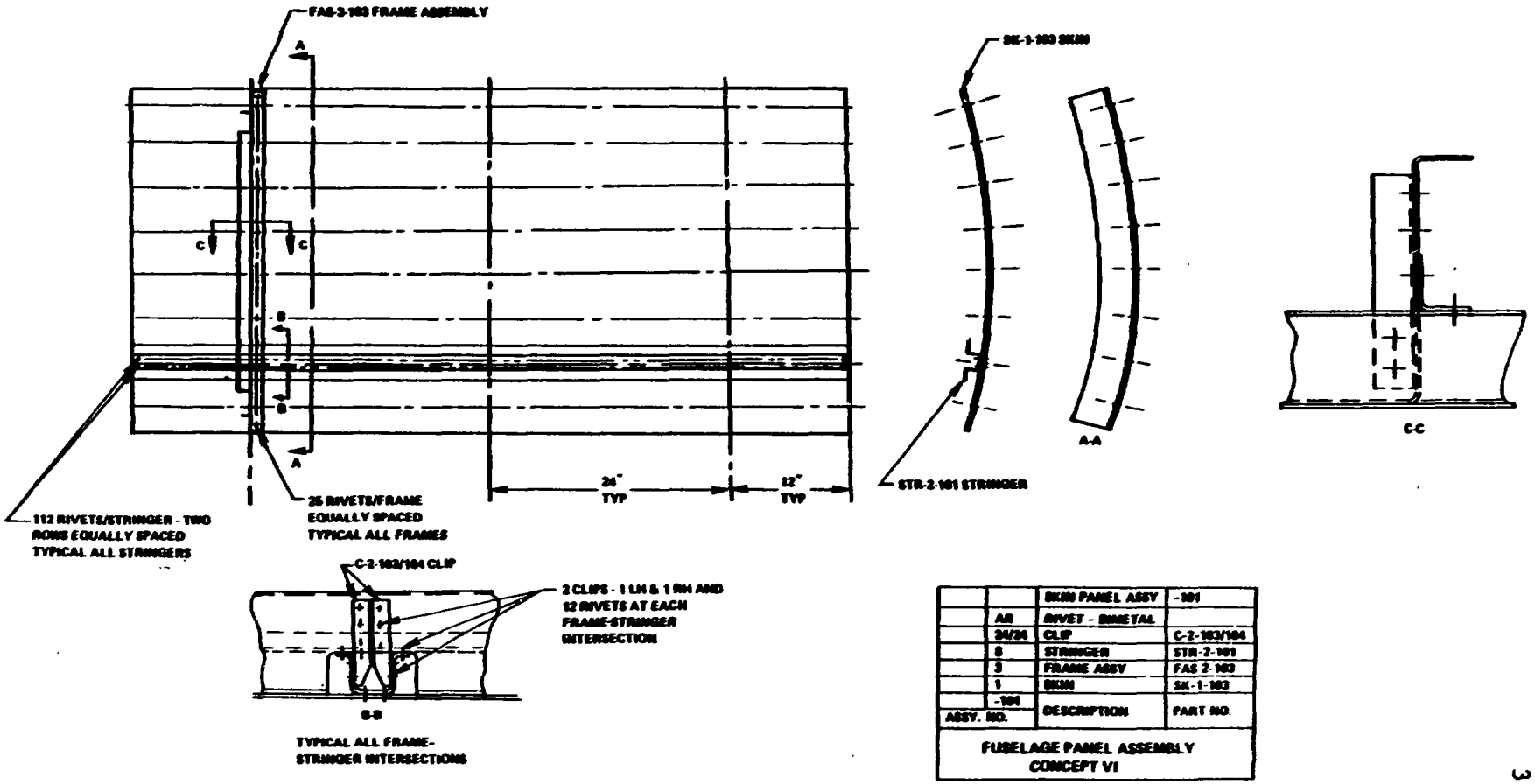
FIGURE 4.8-20. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. IV




| ASSY. NO. | | DESCRIPTION | PART NO. |
|---|---|---|---|
| | | SKIN PANEL ASSY | -101 |
| | AR | RIVET - BIMETAL | |
| | 32/32 | CLIP | C-2-101,102 |
| | 8 | STRINGER | STR-2-101 |
| | 4 | FRAME ASSY | FAS 3-101 |
| | 1 | SKIN | SK-1-103 |
| | -101 | | |

FUSELAGE PANEL ASSEMBLY
CONCEPT V

FIGURE 4.8-21. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. V




| ASSY. NO. | | DESCRIPTION | PART NO. |
|---|---|---|---|
| | | SKIN PANEL ASSY | -101 |
| | AR | RIVET - BIMETAL | |
| | 24/24 | CLIP | C-2-103/104 |
| | 8 | STRINGER | STR-2-101 |
| | 3 | FRAME ASSY | FAS 2-103 |
| | 1 | SKIN | SK-1-103 |
| | -101 | | |

FUSELAGE PANEL ASSEMBLY
CONCEPT VI

FIGURE 4.8-22. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. VI

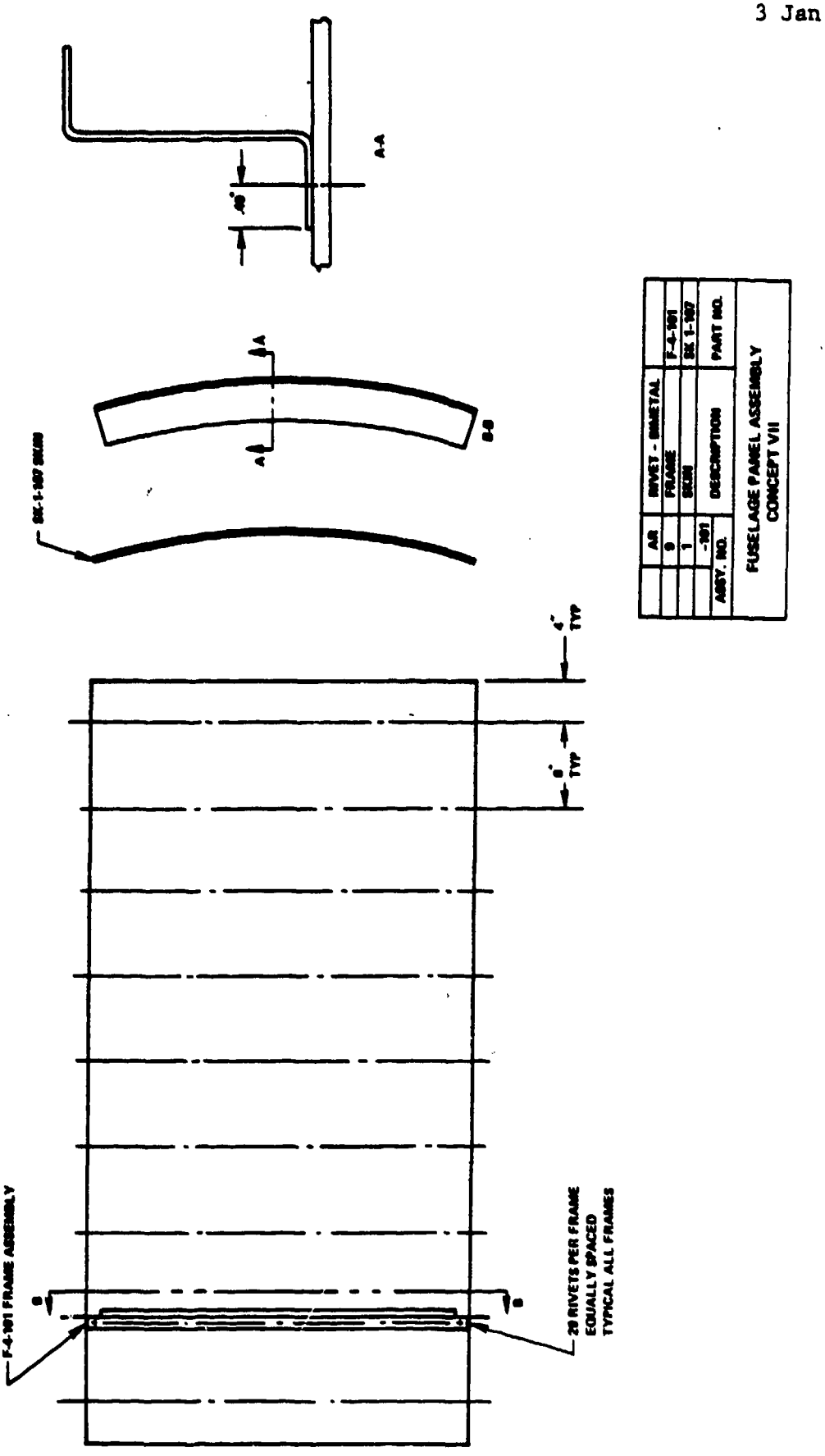



FIGURE 4.8-23. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. VII

TABLE 4.8-7. SUMMARY OF CANDIDATE PANEL CONFIGURATIONS IN TITANIUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

| CONCEPT | SKIN THICKNESS* (IN.) | STRINGERS | | | FRAME ASSEMBLY | | FRAME (ZEE) | | FRAME ANGLE | CLIP (ANGLE) | NO. OF RIVETS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NO. | THICKNESS (IN.) | TYPE | NO. OF FRAMES | NO. OF RIVETS | NO. | THICKNESS (IN.) | | | |
| I | .080 | (9) | .050 | ZEE | 4 | 29 | (4) | .040 | (4) .040 | (36) .040 | 761 |
| II | .080 | (9) | .050 | ZEE | 3 | 29 | (3) | .050 | (3) .050 | (27) .050 | 690 |
| III | 0.0625 | (8) | .040 | HAT** | 4 | 13 | (4) | .040 | (4) .040 | 32 LH .040<br>32 RH .040 | 1380 |
| IV | 0.0625 | (8) | .040 | HAT** | 3 | 13 | (3) | .050 | (3) .050 | 24 LH .050<br>24 RH .050 | 1259 |
| V | .075 | (8) | .040 | HAT*** | 4 | 13 | (4) | .040 | (4) .040 | 32 LH .040<br>32 RH .040 | 1380 |
| VI | .075 | (8) | .040 | HAT*** | 3 | 13 | (3) | .050 | (3) .050 | 24 LH .050<br>24 RH .050 | 1259 |
| VII | .190 | NONE | | | NONE | | (9) | .040 | NONE | NONE | 261 |

*SKIN SIZE: 36" x 72".
**FLANGES ATTACH TO SKIN.
***FLANGES AWAY FROM SKIN.

TABLE 4.8-8. MC/DG COST WORKSHEET

CONCEPT NO. I: 9 ZEE STRINGER/4 FRAME ASSEMBLY

PAGE 1 OF 2

| DESIGN CONCEPT | | RECURRING COST (RC) | | | | | | | | | NON-RECURRING COST (NRC) | | | PROGRAM COST | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L . LC . LR = LS + MS = RC . P/AC . DQ = PRC | | | | | | | | | NRC . LR = PNRC | | | 9 + 12 ÷ DQ = COST/AC | | |
| PART NO. | DESCRIPTION | LABOR MC/DG MH/PT (1) | LC FACTOR (2) | LABOR RATE $/MH (3) | LABOR RC $/PT (4) | MAT'L $/PT (5) | REC. COST/ PT. $ (6) | PARTS PER AC (7) | DES. QTY. (8) | PROG. RC $ (9) | NRC MC/DG MH (10) | LABOR RATE $/MH (11) | PROG. NRC $ (12) | PROG. COST $ (13) | DES. QTY. (14) | COST/ AC $ (15) |
| 1 | SKIN | 1.94 | 1.17 | 25 | 57 | 504 | 561 | 1 | 200 | 112,200 | 108 | 25 | | | 200 | |
| 2 | STRINGER-ZEE | 0.41 | 1.17 | 25 | 12 | 34 | 46 | 9 | 200 | 82,800 | 57 | 25 | | | 200 | |
| 3 | FRAME-ZEE | 1.00 | 1.17 | 25 | 29 | 43 | 72 | 4 | 200 | 57,600 | 225 | 25 | | | 200 | |
| 4 | FRAME-ANGLE | 0.70 | 1.17 | 25 | 20 | 21 | 41 | 4 | 200 | 32,800 | 220 | 25 | | | 200 | |
| 5 | CLIP | 0.12 | 1.17 | 25 | 3.5 | 0.4 | 3.9 | 36 | 200 | 28,080 | 38 | 25 | | | 200 | |
| | FRAME ASSEMBLY | 1.82 | 1.30 | 25 | 59 | 10 | 69 | 4 | 200 | 55,200 | 320 | 25 | | | 200 | |
| | PANEL ASSEMBLY | 14.55 | 1.66 | 25 | 604 | 266 | 870 | 1 | 200 | 174,000 | 520 | 25 | | | 200 | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | TOTALS | | | | | | | | | 542,680 | 1,488 | 25 | 37,200 | 579,880 | 200 | 2,899 |

BY: Jerry M. Pelton

DATE: JUNE 20, 1979

TABLE 4.8-9. COST WORKSHEET - SUPPORTING DATA

CONCEPT NO. I: 9 ZEE STRINGER/4 FRAME ASSEMBLY

PAGE 2 OF 2

| | |
|---|---|
| PART: SKIN<br>BASE PART-CED-T-7 1.51 MH/PT TOOL 70 MH<br>DICE-13 0.43 " " 38 "<br>TOTAL 1.94 MH/PT 108 MH<br>MATERIAL* - 0.080"<br>3'x6' = 18 SQ.FT. @ $28/SQ.FT. = $504/PART | PART: STRINGER-ZEE<br>BASE PART-CED-T-5 0.41 MH/PT TOOL 57 MH<br>BRAKE FORM R.T. (5T BR)<br>MATERIAL* - 0.050"<br>3.5"/12 x 6' = 1.75 SQ.FT. @ $19.50/SQ.FT. = $34/PART |
| PART: FRAME, ZEE<br>BASE PART-CED-T-6 1.0 MH/PT TOOL 225 MH<br>HOT STRETCH<br>MATERIAL* 0.040"<br>10" x 36"/144 = 2.5 SQ.FT. @ $17/SQ.FT. = $42.50/PART | PART: FRAME, ANGLE<br>BASE PART-CED-T-2 0.70 MH/PT TOOL 220 MH<br>HOT SIZE<br>MATERIAL* 0.040"<br>5"/12 x 3' = 1.25 SQ.FT. @ $17/SQ.FT. = $21.25 PART |
| PART: CLIP<br>BASE PART-CED-T-1 0.12 MH/PT TOOL 38 MH<br>BRAKE FORM R.T. (5T BR)<br>MATERIAL* 0.040"<br>3.5" x 1"/144 = 0.024 SQ.FT. @ $17/SQ.FT. = $0.41/PART | PART: |
| ASSEMBLY: FRAME<br>CED-MFA-2 and CED-MFA-3 MANUAL, DRY TOOL 320 MH<br>29 RIVETS/ASSEMBLY 1.82 MH/ASSEMBLY<br>MATERIAL-AVERAGE RIVET COST $0.35 EACH**<br>29 RIVETS @ $0.35 = $10.15/ASSEMBLY | ASSEMBLY: PANEL<br>CED-MFA-2 and CED-MFA-3 AUTO/MAN, DRY TOOL 520 MH<br>761 RIVETS/ASSEMBLY 14.55 MH<br>MATERIAL-AVERAGE RIVET COST $0.35 EACH**<br>761 RIVETS @ $0.35 = $266.35 |

* MATERIAL COSTS ARE FROM FORMATS DEVELOPED BY MC/DG USER COMPANIES, PER GROUND-RULES. MATERIAL COSTS ARE NOT PRESENTED IN THE MC/DG.

** FROM PROCUREMENT

TABLE 4.8-10. INSTRUCTIONS FOR UTILIZING DESIGNER'S WORKSHEET

| Step No. | Worksheet Column | Input | Procedure |
|---|---|---|---|
| 1 | | Part no. | Enter identification, if available. |
| 2 | | Description | Enter brief description, e.g., Stiffener, Zee, J section, etc. |
| 3 | 1 | Manufacturing Labor | From CED section determine man-hours per part at 200 units. |
| 4 | 2 | Learning curve (LC) factor | Based upon learning curve percentage and design quantity. Factor provided by user company. |
| 5 | 3 | TI&E labor | From MC/DG, enter RC for TI&E (man-hours). |
| 6 | 4 | Labor rate | Current manufacturing labor rate including direct labor fringe benefits and overhead charges. |
| 7 | 5 | Labor recurring costs (RC) | Product of Column 1 times Column 2 plus Column 3 times Column 4. |
| 8 | 6 | Material cost | Based upon furnished data in company utilizing MC/DG, enter material cost per part in dollars. |
| 9 | 7 | Recurring cost (RC) per part | Total of Columns 5 and 6. |
| 10 | 8 | Parts per aircraft | Number of identical parts per aircraft. |
| 11 | 9 | Design quantity | Number of aircraft in buy considered. |
| 12 | 10 | Program recurring cost (RC) | Product of Column 7 times Column 8 times Column 9. |
| 13 | 11 | Nonrecurring tooling cost (NRTC) | From MC/DG, enter NRTC in man-hours. |
| 14 | 12 | NRTC for TI&E | From MC/DG, enter NRTC for TI&E in man-hours. |
| 15 | 13 | Labor rate | See Column 3. |
| 16 | 14 | Program nonrecurring tooling costs (NRTC) | Columns 11 plus 12 times Column 13. |
| 17 | 15 | Program cost | Sum of Column 10 and Column 14. |
| 18 | 16 | Design quantity | See Column 9. |
| 19 | 17 | Cost per aircraft | Column 15 divided by Column 16. |

TABLE 4.8-11. LEARNING CURVE FACTORS

| OPERATION | TYPICAL INDUSTRY LEARNING CURVE | |
|---|---|---|
| ASSEMBLY, CONTROLS | 85% | |
| ASSEMBLY, ELECTRICAL | 80% | |
| ASSEMBLY, HYDRAULICS, PNEUMATIC, ETC. | 85% | |
| FUNCTIONAL INSTALLATION | 65% | |
| PLASTIC FABRICATION | 85% | |
| MACHINING – CONVENTIONAL | 90% | |
| MACHINING – NUMERICAL CONTROL | 95% | |
| STRUCTURAL ASSEMBLY – BENCH | 85% | FRAME SUBASSEMBLY |
| STRUCTURAL ASSEMBLY – FLOOR | 75% | PANEL ASSEMBLY |
| STRUCTURAL ASSEMBLY – FINAL | 70% | |
| SHEET METAL FABRICATION | 90% | DETAIL PARTS |

NOTE: THIS GUIDE IS TYPICAL OF THE AEROSPACE INDUSTRY AND IS FOR THOSE DESIGNERS FOR WHOM INDIVIDUAL COMPANY LEARNING CURVES ARE NOT AVAILABLE.

THE FACTORS IN THIS TABLE WILL CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED.

| DESIGN QUANTITY | LEARNING CURVE – PERCENT | | | | | | |
|---|---|---|---|---|---|---|---|
| | 95 | 90 | 85 | 80 | 75 | 70 | 65 |
| 1 | 1.48 | 2.25 | 3.48 | 5.50 | 9.00 | 15.00 | 27.00 |
| 10 | 1.33 | 1.79 | 2.47 | 3.48 | 5.04 | 7.53 | 11.67 |
| 25 | 1.25 | 1.59 | 2.05 | 2.71 | 3.68 | 5.13 | 7.43 |
| 50 | 1.19 | 1.44 | 1.79 | 2.22 | 2.85 | 3.76 | 5.14 |
| 100 | 1.13 | 1.30 | 1.52 | 1.80 | 2.18 | 2.73 | 3.51 |
| 200 | 1.08 | 1.17 | 1.30 | 1.45 | 1.66 | 1.95 | 2.36 |
| 350 | 1.04 | 1.08 | 1.14 | 1.22 | 1.33 | 1.48 | 1.70 |
| 500 | 1.01 | 1.02 | 1.05 | 1.09 | 1.15 | 1.24 | 1.38 |
| 750 | 0.98 | 0.96 | 0.96 | 0.96 | 0.97 | 1.01 | 1.09 |
| 1000 | 0.96 | 0.92 | 0.89 | 0.87 | 0.87 | 0.88 | 0.91 |

TABLE 4.8-12. COST-WEIGHT TRADE-OFF SUMMARY FOR TITANIUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

| CONCEPT | COST | | WEIGHT | | COST OF WEIGHT SAVED-- $/LB |
|---|---|---|---|---|---|
| | $/PANEL | Δ$/PANEL | LBS/PANEL. | ΔWT LBS | |
| I | 2889 | 871 | 59.02 | -28.77 | 30 |
| II | 2650 | 622 | 58.46 | -29.33 | 21 |
| III | 4182 | 2154 | 58.26 | -29.53 | 73 |
| IV | 3728 | 1700 | 57.58 | -30.21 | 56 |
| V | 4236 | 2208 | 64.48 | -23.31 | 95 |
| VI | 3782 | 1754 | 63.80 | -23.99 | 73 |
| VII | 2028 | BASE | 87.79 | BASE | BASE |

RECOMMENDED CONCEPT

TABLE 4.8-13. COST-WEIGHT TRADE-OFF SUMMARY FOR TITANIUM FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

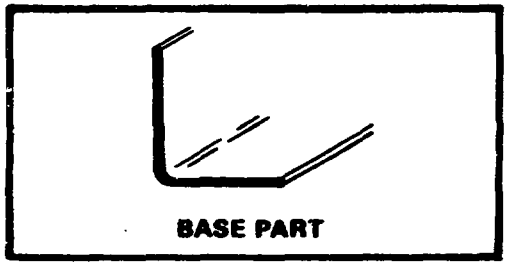
| CONCEPT | COST | | WEIGHT | | COST OF WEIGHT SAVED-- $/LB |
|---|---|---|---|---|---|
| | $/PANEL | Δ$/PANEL | LBS/PANEL | ΔWT LBS | |
| I | 2899 | 249 | 59.02 | +0.56 | (1) |
| II | 2650 | BASE | 58.46 | BASE | BASE |
| III | 4182 | 1532 | 58.26 | -0.20 | 7660 |
| IV | 3728 | 1078 | 57.58 | -0.88 | 1225 |
| V | 4236 | 1586 | 64.48 | +6.02 | (1) |
| VI | 3782 | 1132 | 63.80 | +5.34 | (1) |

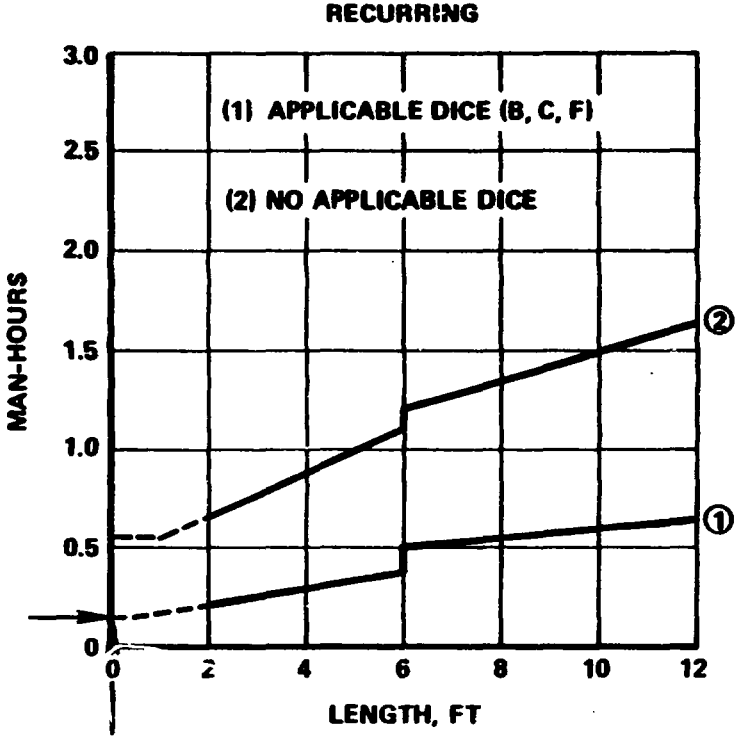
RECOMMENDED CONCEPT

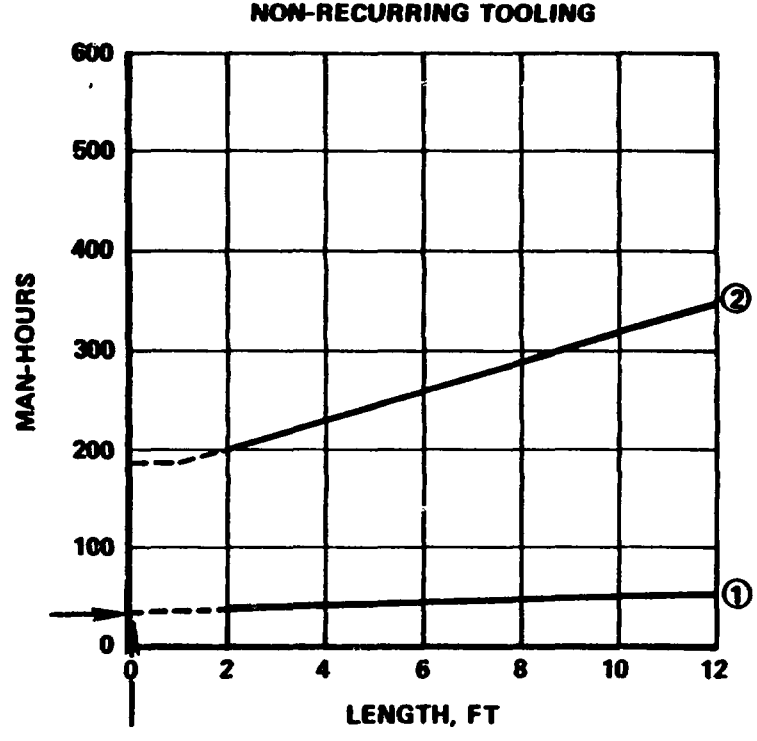
(1) GREATER WEIGHT AND GREATER COST.

# TITANIUM ANGLE, STRAIGHT MEMBER, LOWEST COST PROCESS

## BRAKE FORM OR PREFORM/HOT SIZE




(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t

(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

CED—T-1

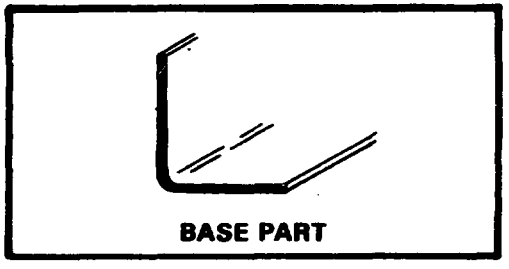
FIGURE 4.8-24. FORMAT USED IN TRADE-OFF STUDY

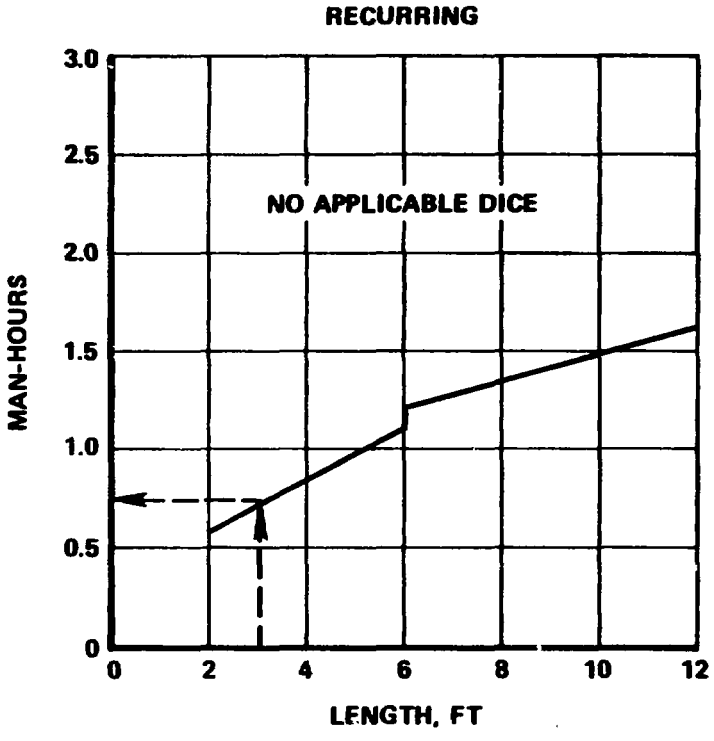


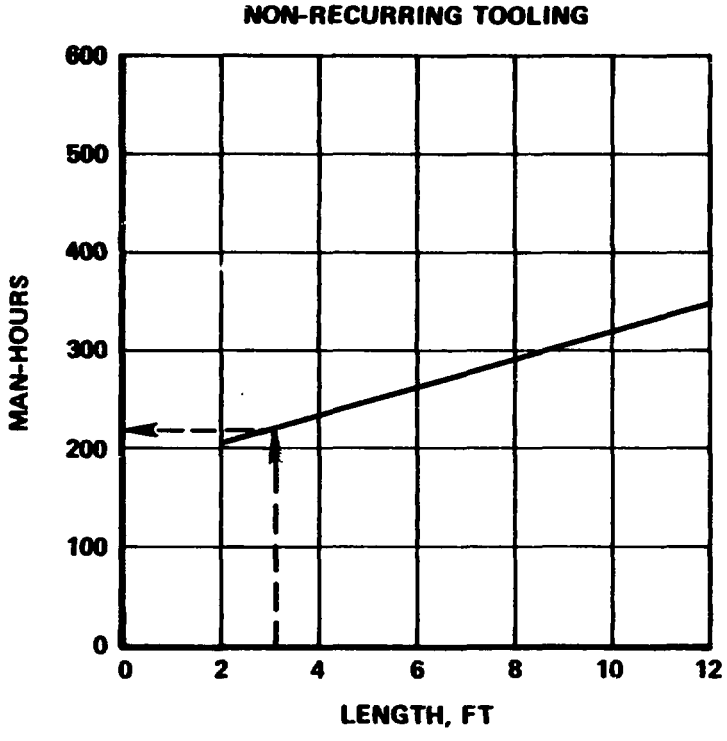
FTR450261000U
3 Jan 1983

# TITANIUM ANGLE, CONTOURED MEMBER, LOWEST COST PROCESS

## PREFORM/HOT SIZE




MINIMUM BEND RADIUS = 2t

CED—T-2

FIGURE 4.8-25. FORMAT USED IN TRADE-OFF STUDY

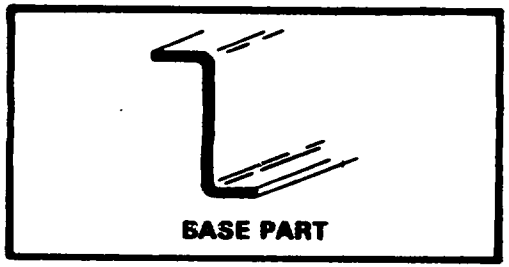


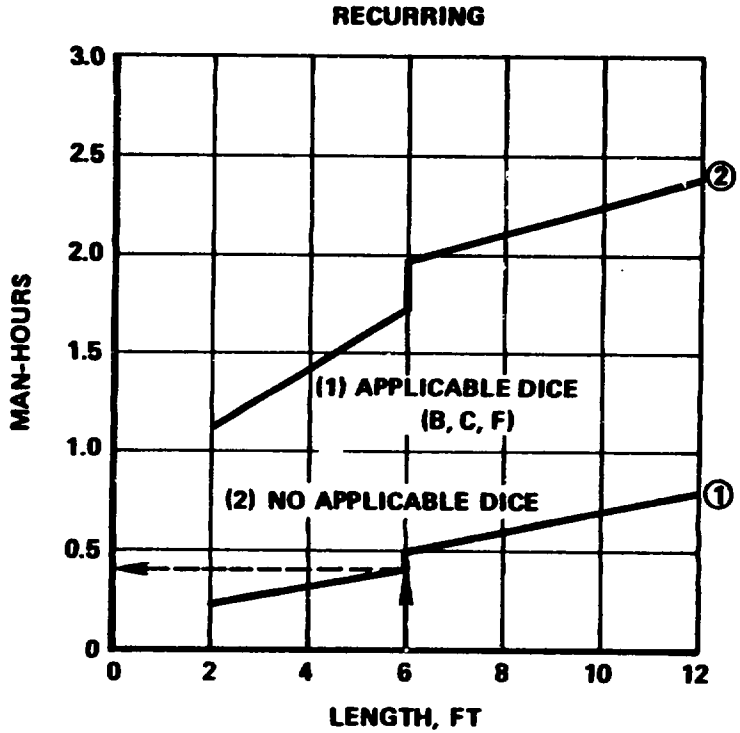
FTR450261000U
3 Jan 1983

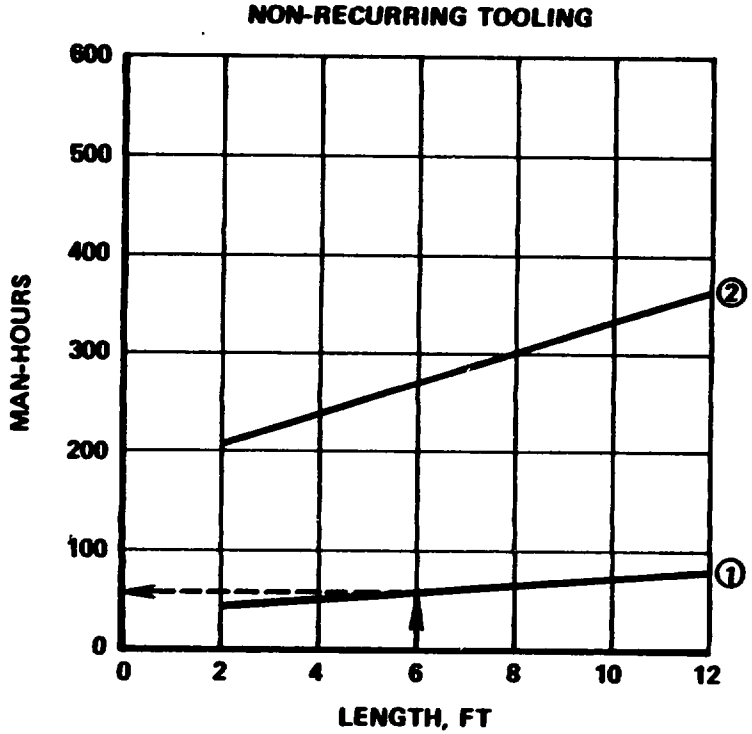
FIGURE 4.8-26

# TITANIUM ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

## BRAKE FORM OR PREFORM/HOT SIZE




(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t
(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

CED—T-5

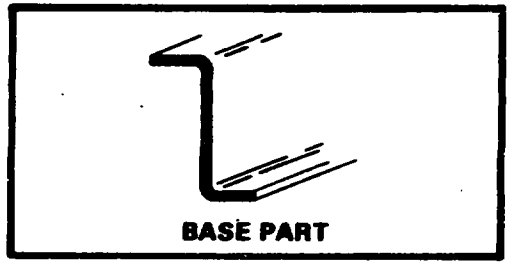
FIGURE 4.8-26. FORMAT USED IN TRADE-OFF STUDY

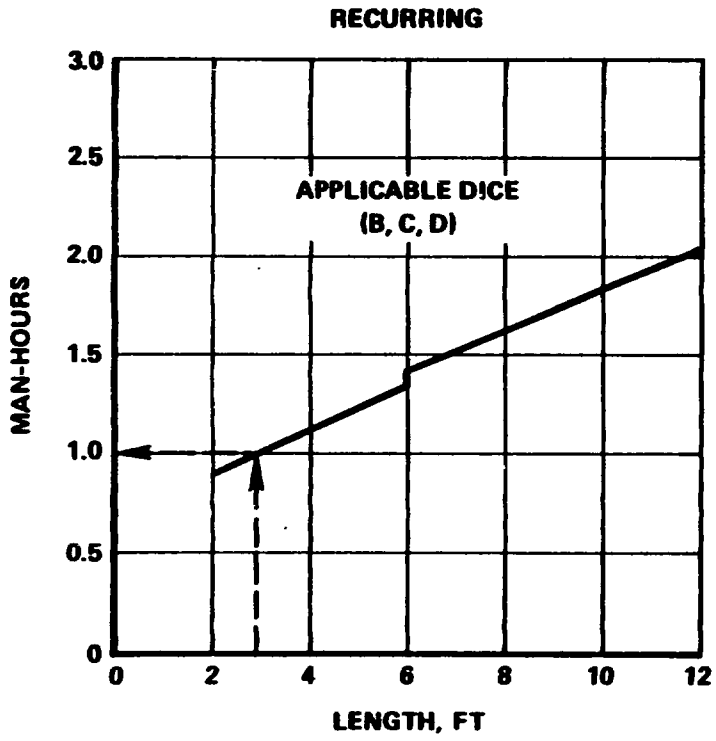


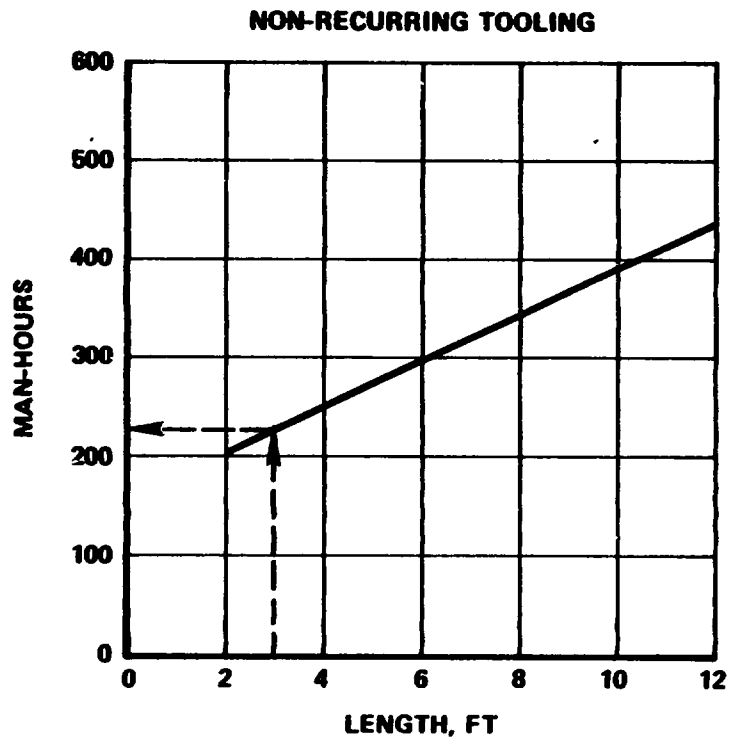
FTR450261000U
3 Jan 1983

# TITANIUM ZEE, CONTOURED MEMBER,* LOWEST COST PROCESS

## BRAKE/HOT STRETCH




MINIMUM BEND RADIUS = 2t

*NO REVERSE CURVATURE

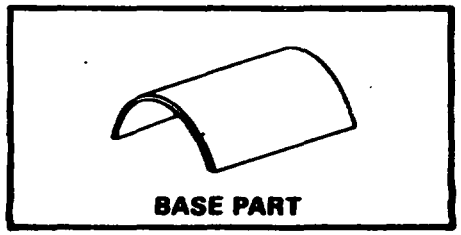
CED—T-6

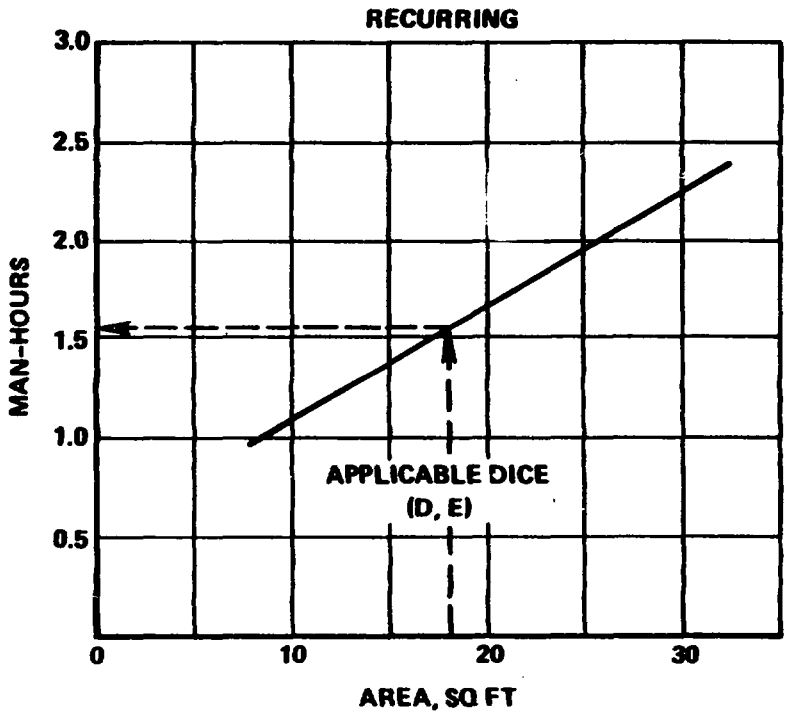
FIGURE 4.8-27. FORMAT USED IN TRADE-OFF STUDY

FTR450261000U
3 Jan 1983

# TITANIUM CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS

## FARNHAM ROLL



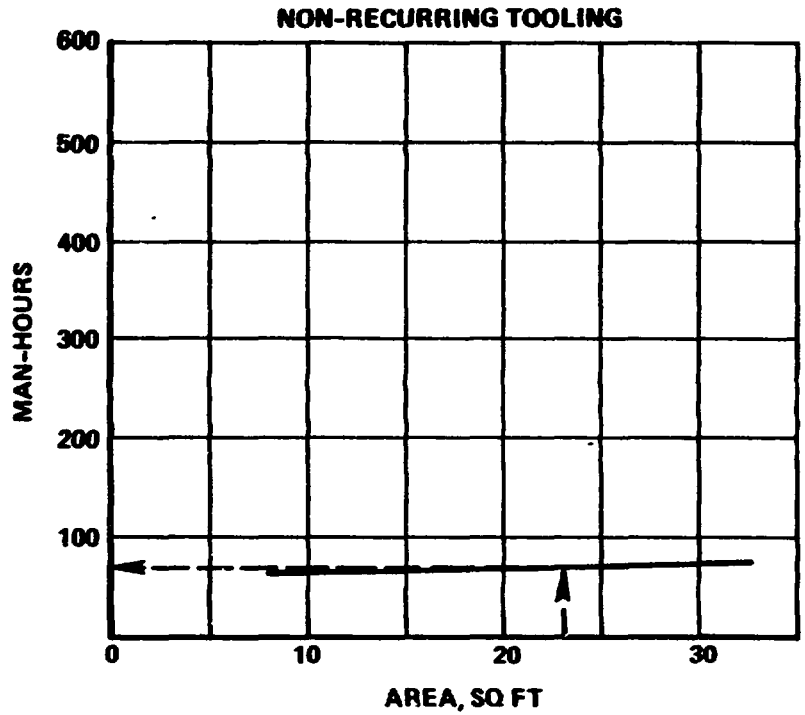



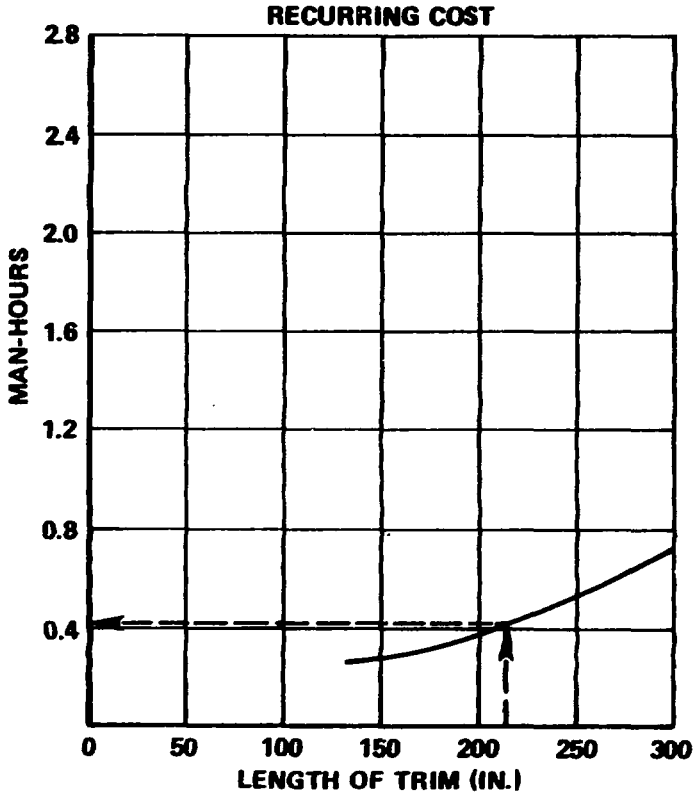

FIGURE 4.8-28. FORMAT USED IN TRADE-OFF STUDY

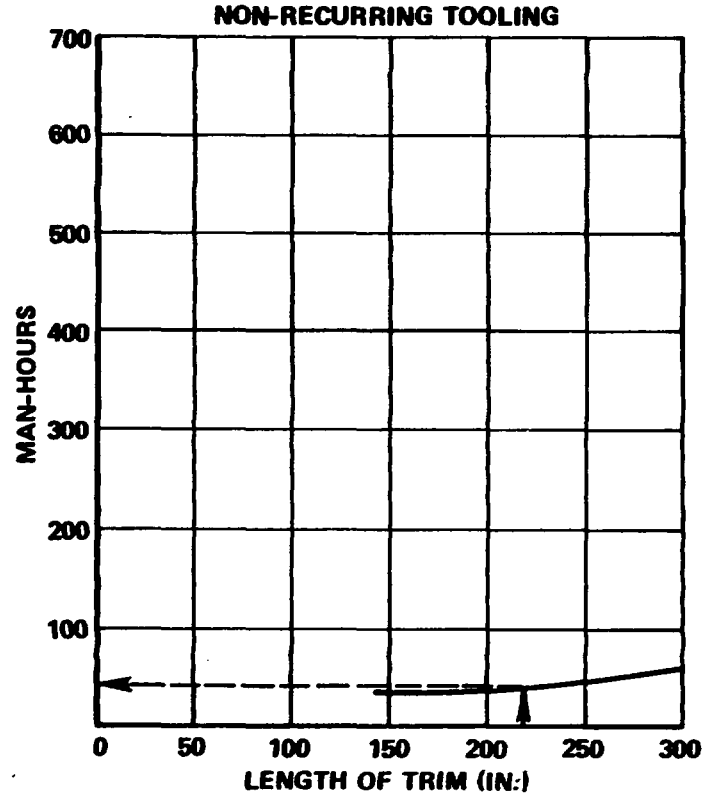
CED—T-7



FTR450261000U
3 Jan 1983

# TITANIUM PANELS
# TRIM AFTER FORMING




DICE-13

FIGURE 4.8-29. FORMAT USED IN TRADE-OFF STUDY

# INSTALLATION COSTS FOR TITANIUM RIVETS (CONCEPT I)

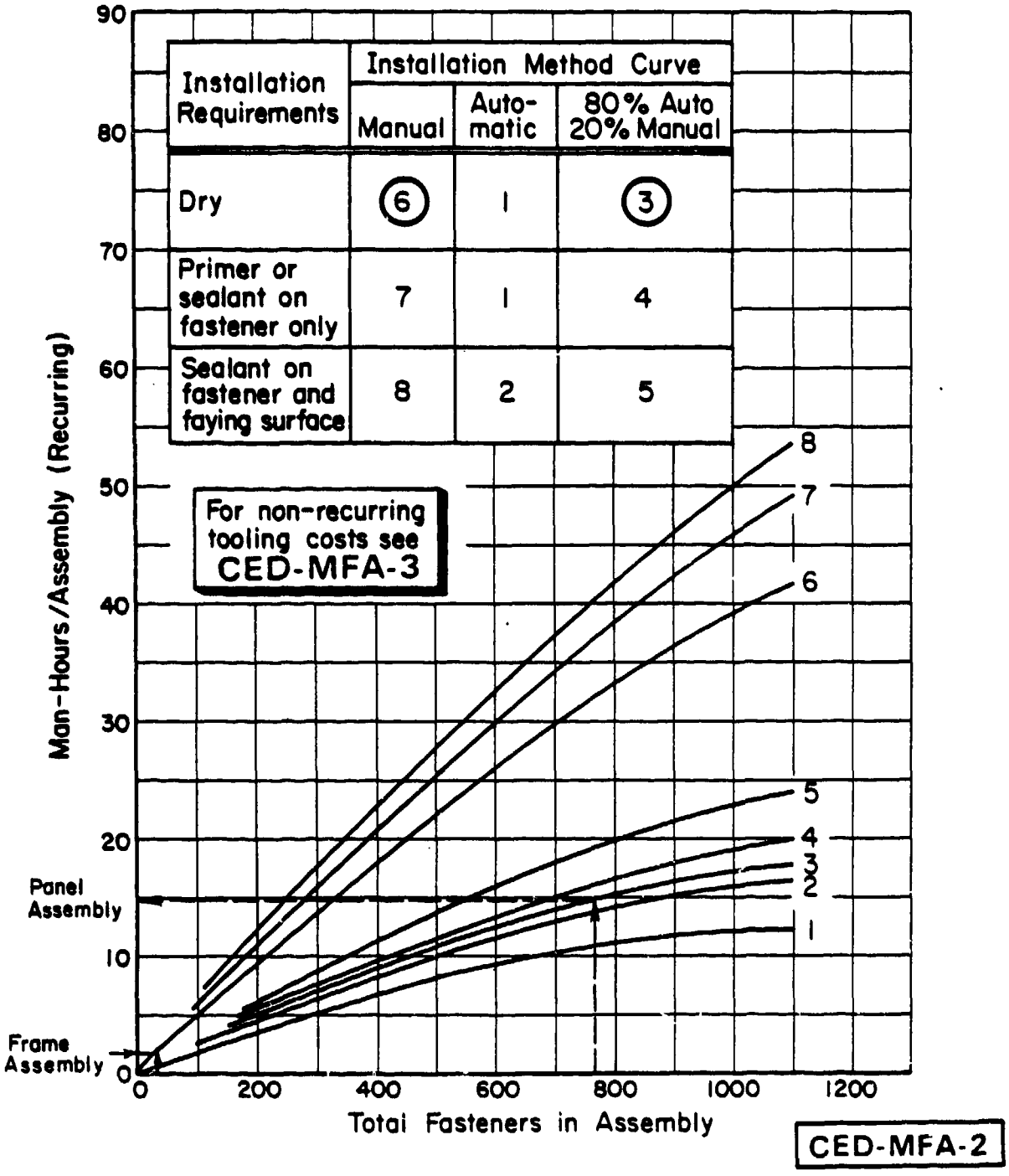
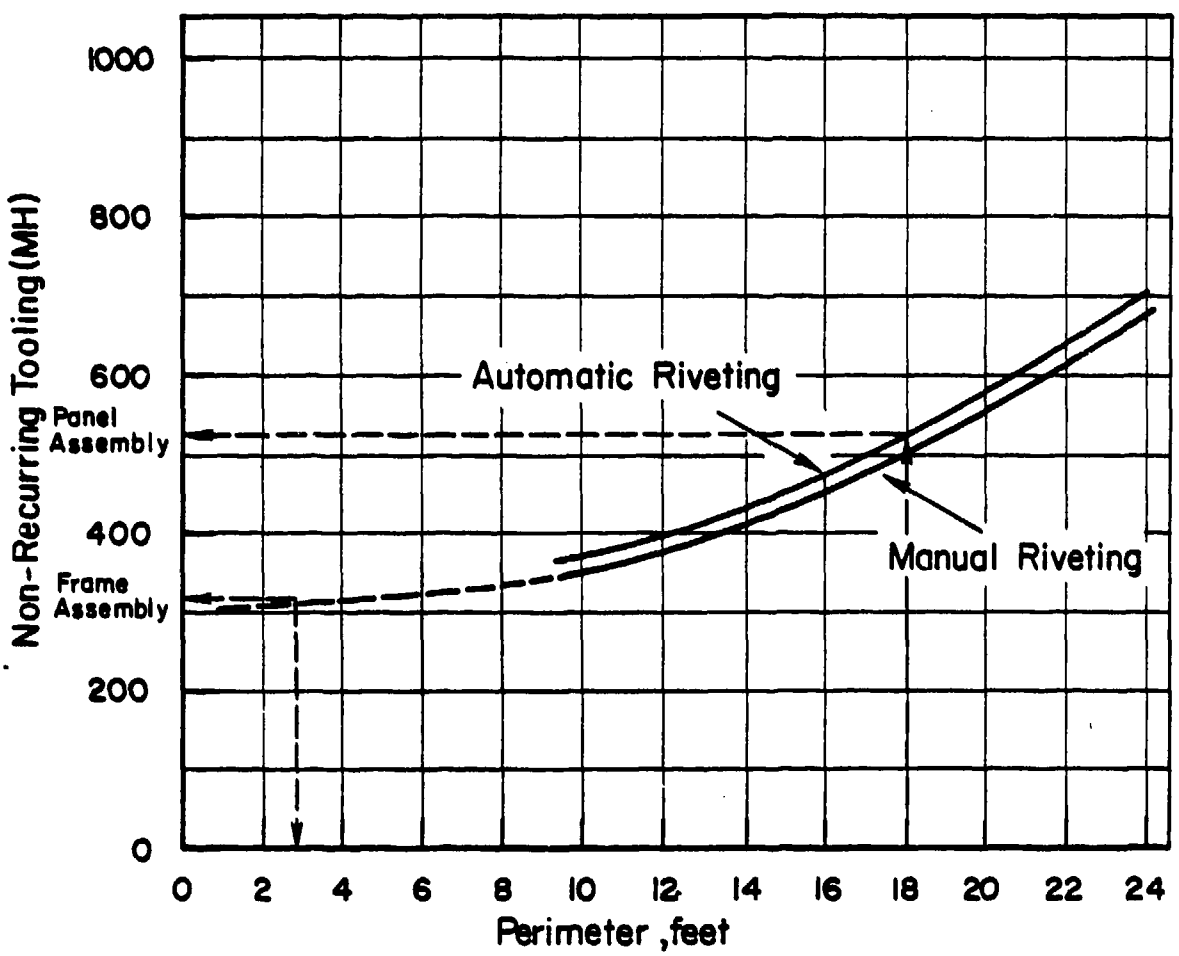



FIGURE 4.8-30. FORMAT USED IN TRADE-OFF STUDY

# NON-RECURRING TOOLING COST FOR ALUMINUM AND TITANIUM ASSEMBLIES (CONCEPT I)




CED-MFA-3

FIGURE 4.8-31. FORMAT USED IN TRADE-OFF STUDY

### 4.8.4 Composite Fuselage Panel

The details of the trade-off study conducted on a composite (graphite/epoxy) fuselage panel are discussed in this chapter. The trade-off followed the steps similar to the earlier cost/weight analyses. These steps are:

1. Develop candidate conceptual designs
   - Establish skin panel sizing
   - Establish frame shape selection
   - Identify number of frames required
   - Select stringer shapes
   - Identify number of stringers required
   - Recommend candidate manufacturing methods to produce each discrete part
2. Determine manufacturing cost for each candidate design
3. Determine assembly costs for each candidate design
4. Determine weight (lb) for each panel candidate design
5. Determine total manufacturing cost (including materials and tooling)
6. Present manufacturing man-hours or cost and structural weight on design charts or tables to facilitate selection of the most cost-effective design.

Because advanced composite material applications to aircraft fuselages are promising, this is an appropriate study. Advanced composites applied to fuselages provide several advantages. Fabrication of metallic fuselages by conventional methods has resulted in problems with manufacturing cost, weight, maintenance, crashworthiness, and fatigue resistance. Use of lightweight sandwich panels has increased stiffness, but corrosion, damage control, and repair have posed problems. The large number of parts and fasteners, typical of metallic assemblies, also impacts ownership costs (approximately 75 percent) and life-cycle costs (approximately 50 percent). Conversely, the utilization of advanced composite materials has provided both weight and cost savings in primary structures. Emerging manufacturing methods for advanced composites promise further significant reductions in acquisition costs of advanced tactical aircraft and the cost advantages of these methods should also be presented to designers.

The composite used in this trade-off was AS/3501-6, as specified in the ground rules (see ground rules in MC/DG Composites Section 4.3). The design assumptions for this trade-off specified a panel 36 inches wide by 72 inches long, with single curvature of 60-inch radius. A balanced ply lay-up with quasi-isotropic skin was selected. The spacing of the structural members was specified as 12 to 24 inches for the frames and 4 inches minimum for the stringers. Assembly was to be performed utilizing titaniumfasteners or cocuring. The limit loading conditions were:

- $N_x$ = 2000 lb/in. (compression)
- $N_{xy}$ = 121 lb/in. (shear)
- Shear buckling was not permitted.

A temperature of 300°F and a dry environment were also assumed.

As shown in Figure 4.8-32, the configurations could be conveniently grouped into the following three categories:

- Lightweight/high complexity (Concept A)
- Moderate weight/moderate complexity (Concept B & C)
- High weight/low complexity (Concept D).

In evaluating the various concepts, stringer/frame, stringer/skin, and skin variations were considered. The MC/DG was utilized in analyzing the manufacturing costs of each concept, as indicated by the dashed boxes in Figure 4.8-32. Figures 4.8-33 to 4.8-36 show the baseline fuselage panel and the three configuration categories mentioned above (Concepts A to D).

Three configurations were analyzed within the category of light weight/high complexity (see Table 4.8-14). For these concepts, the number of stringers and frames were varied in the process of determining the optimum combination. Once it was determined that four stringers with three frames provide the optimum combination, the type of stringer and the method of assembly were determined. Table 4.8-14 summarizes the stringer shapes and assembly methods considered and also provides the cost (man-hours), for each concept. Figure 4.8-37 provides a plot of these concepts showing weight versus manufacturing man-hours. The figures also show the relationship of each concept to lines representing the values of man-hours per pound. From Figure 4.8-37, it will be noted that alternative III was selected to represent the lightweight/high complexity category when comparing with the competing concepts.

An example of the MC/DG cost worksheet and the supplementary data sheet are shown for the lightweight/high complexity concept following this summary of the trade-offs (Tables 4.8-15 and 4.8-16). Instructions on utilizing this worksheet are included in Table 4.8-17.

Data from the MC/DG formats were entered in the worksheet in order to calculate the cost of the panel. The formats used for this concept are listed in Table 4.8-18. Examples of formats used for Concept A-III are shown in Figures 4.8-39 to 4.8-46. The formats are marked with dashed lines and arrows to indicate how the data were read. Since this concept utilized ply counts that were not readily indicated on the formats, interpolation was necessary. The nature of the formats makes interpolation an easy task for the designer to perform. The interpolated lines are shown dashed to distinguish them from the lines on the original format.

A similar methodology was followed to select representative configurations from the other two categories. Table 4.8-19 summarizes the configurations chosen for each category with the cost (man-hours) and weight (pounds) of each configuration. Figure 4.8-38 presents this information graphically. Again, lines representing man-hours per pound are included. Using these data, selecting a configuration for production commitment,

from those summarized, depends on the relative importance of weight savings as well as other design factors for the aircraft under consideration. The designer and management can balance weight savings to meet the vehicle requirements, with the cost to achieve these savings.

In a case where two or more concepts appear to be close in the cost/weight trade, cost estimators may need to participate in the decisions by making a detailed cost estimate. This estimate, combined with other factors, would allow the design team to select the most cost-competitive design meeting all design parameters.

This trade-off provided an opportunity to utilize a number of the designer-oriented formats presented in MC/DG Section 4.3 for "Advanced Composites".

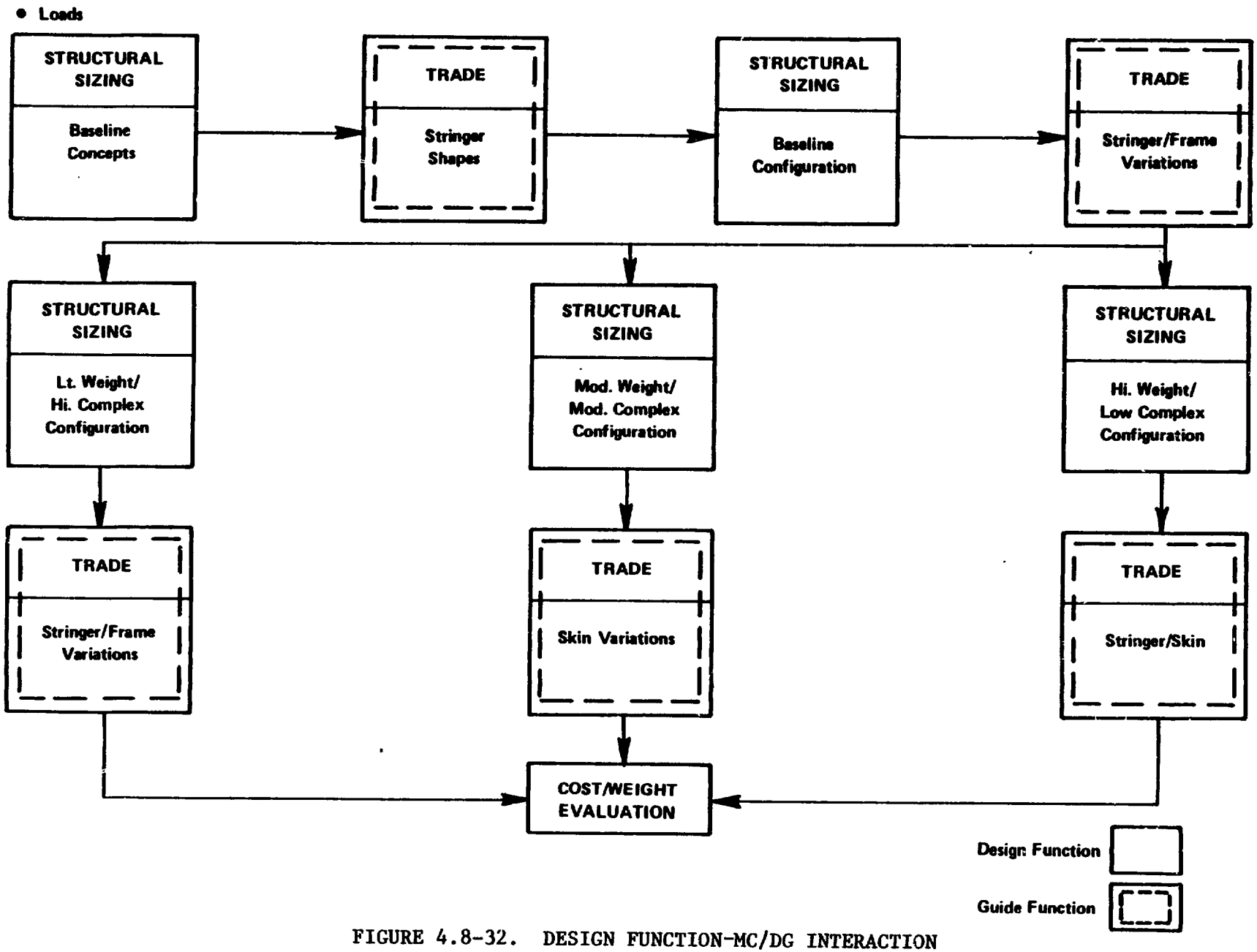



FIGURE 4.8-32. DESIGN FUNCTION-MC/DG INTERACTION



FTR450261000U
3 Jan 1983

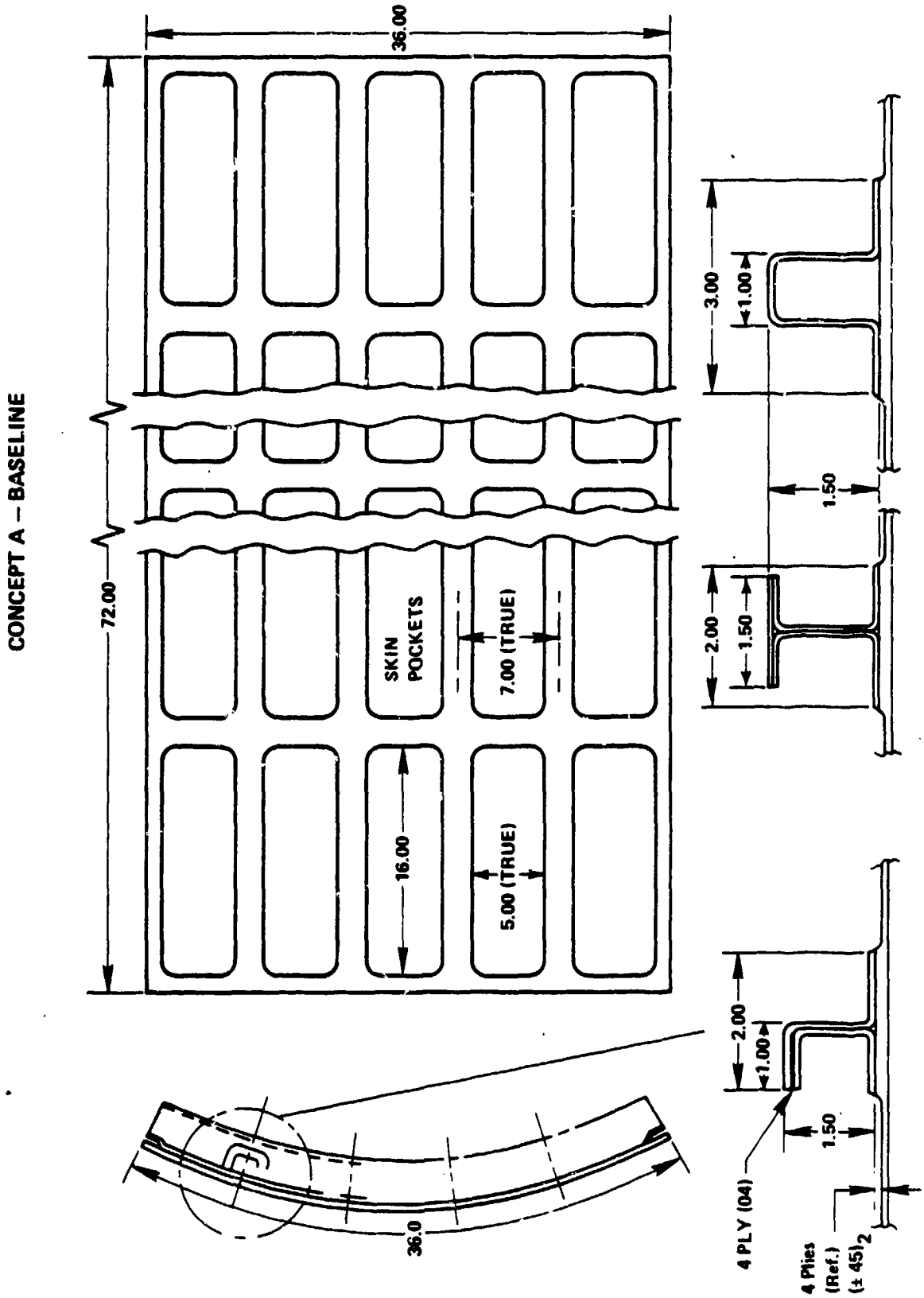



FIGURE 4.8-33. DETAILS OF BASELINE FUSELAGE PANEL IN ADVANCED COMPOSITE TRADE-OFF STUDY

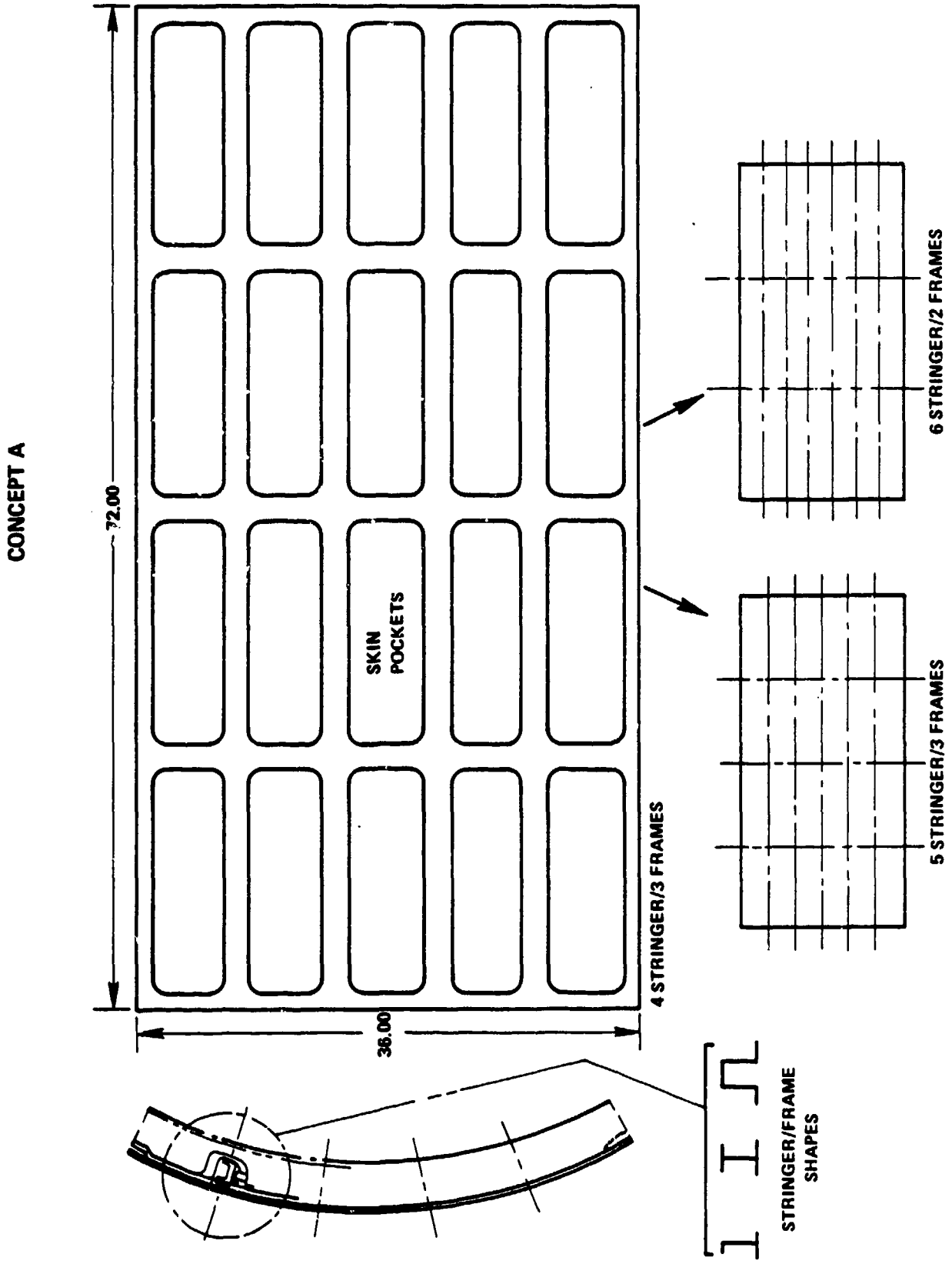



FIGURE 4.8-34. LIGHTWEIGHT/HIGH COMPLEXITY COMPOSITE FUSELAGE PANEL

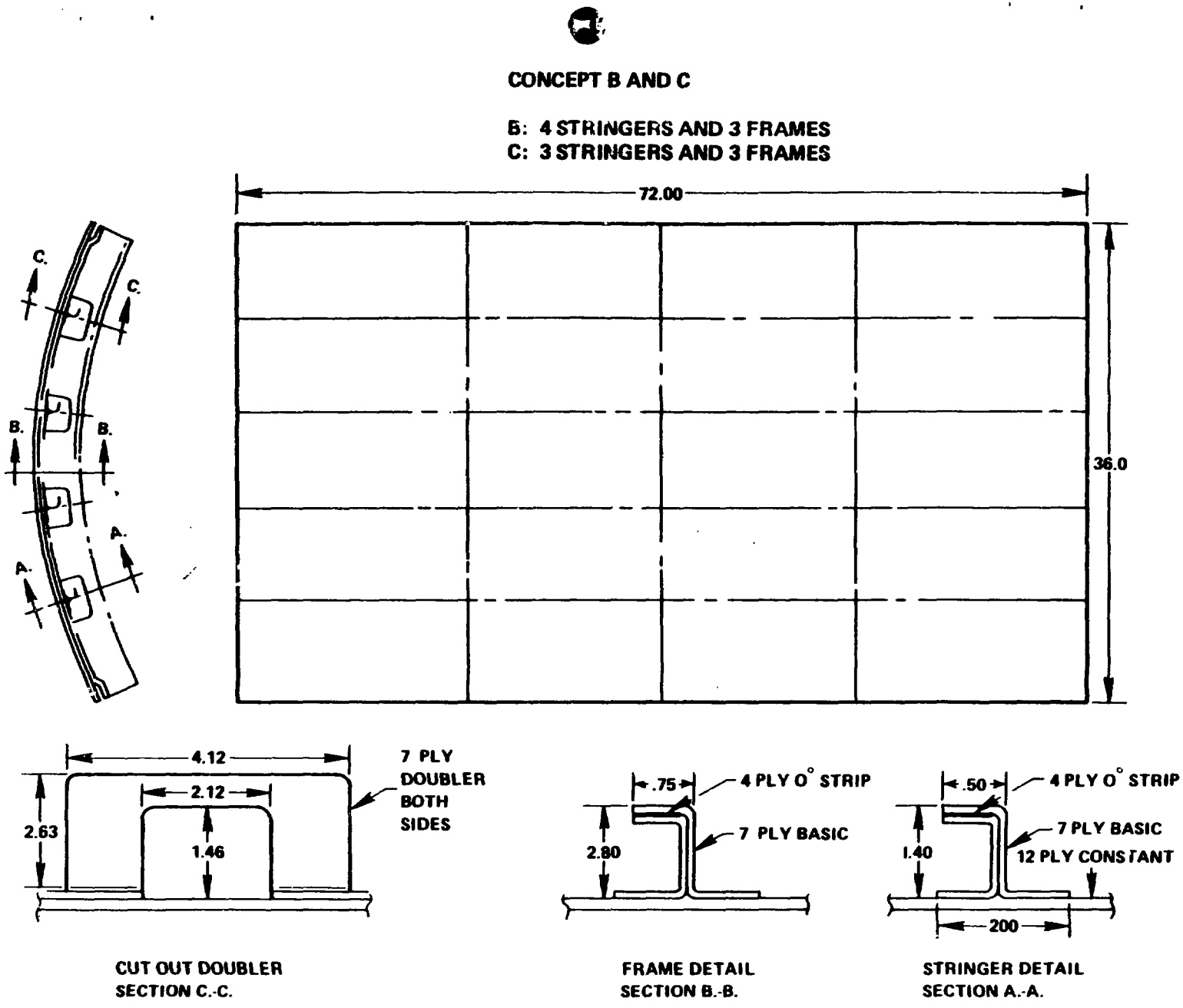



FIGURE 4.8-35. MODERATE WEIGHT/MODERATE COMPLEXITY COMPOSITE FUSELAGE PANEL

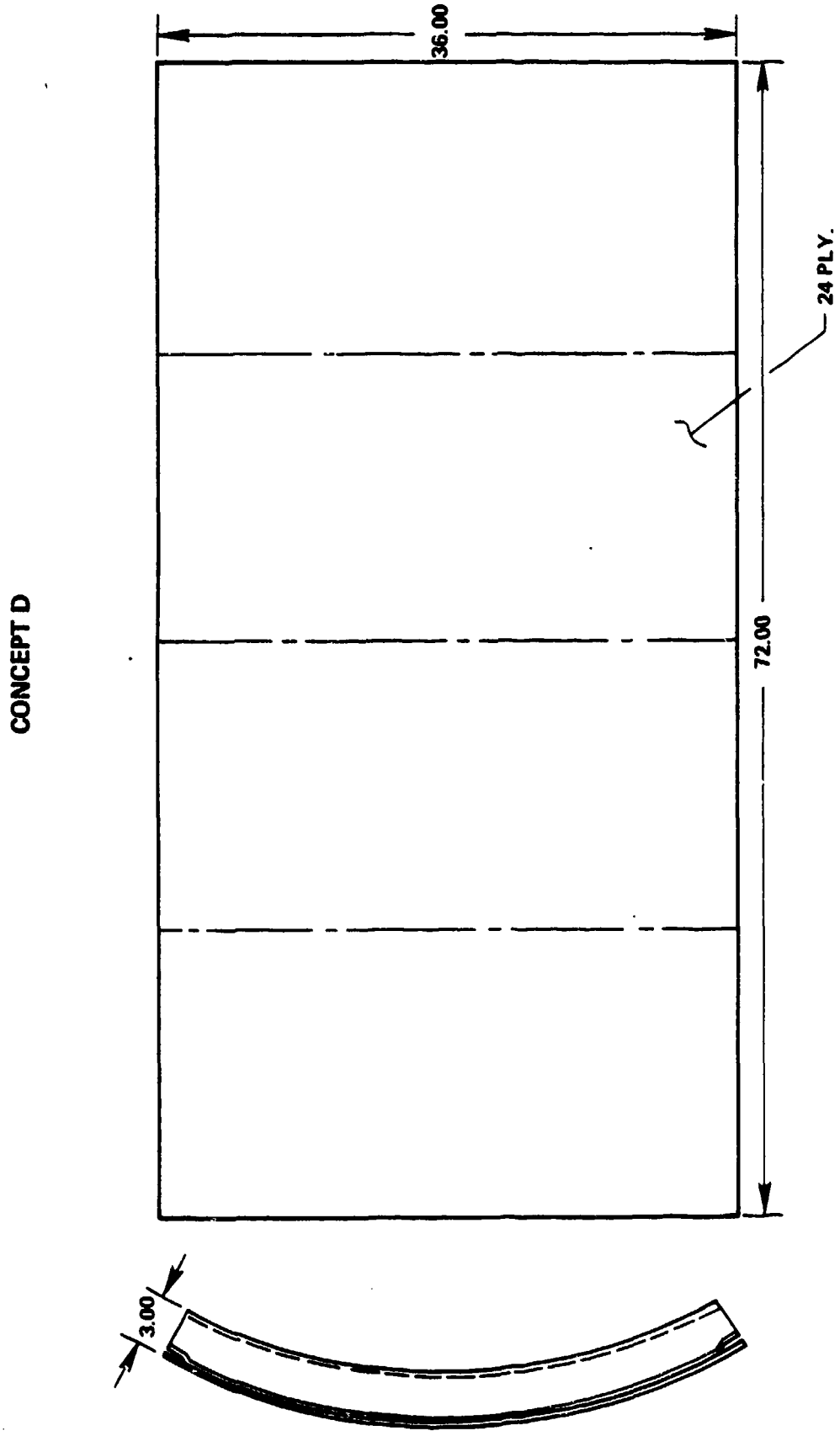
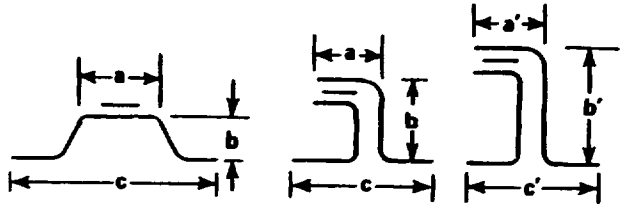



FIGURE 4.8-36. MINIMUM PART COUNT COMPOSITE FUSELAGE PANEL (PLATE SKIN/3 FRAMES)

TABLE 4.8-14. SUMMARY OF DESIGN FEATURES FOR LIGHTWEIGHT/HIGH COMPLEXITY COMPOSITE FUSELAGE CONCEPTS A-I, A-II, & A-III




| CONFIG-URATION | STRINGER | | | | | | FRAME | | | | | COST, MAN-HOURS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TYPE | NO. | a (IN.) | b (IN.) | c (IN.) | ATTACHMENT METHOD | TYPE | NO. | a' (IN.) | b' (IN.) | c' (IN.) | |
| A-I | HAT | 4 | 1.0 | 1.5 | 3.0 | MECHANICALLY FASTENED (100% MANUAL) | J | 3 | 0.75 | 3.0 | 2.0 | 77.9 |
| A-II | HAT | 4 | 1.0 | 1.5 | 3.0 | MECHANICALLY FASTENED (80% AUTOMATIC 20% MANUAL) | J | 3 | 0.75 | 3.0 | 2.0 | 61.5 |
| A-III | J | 4 | 1.0 | 1.5 | 2.0 | COCURED | J | 3 | 0.75 | 3.0 | 2.0 | 51.1 |

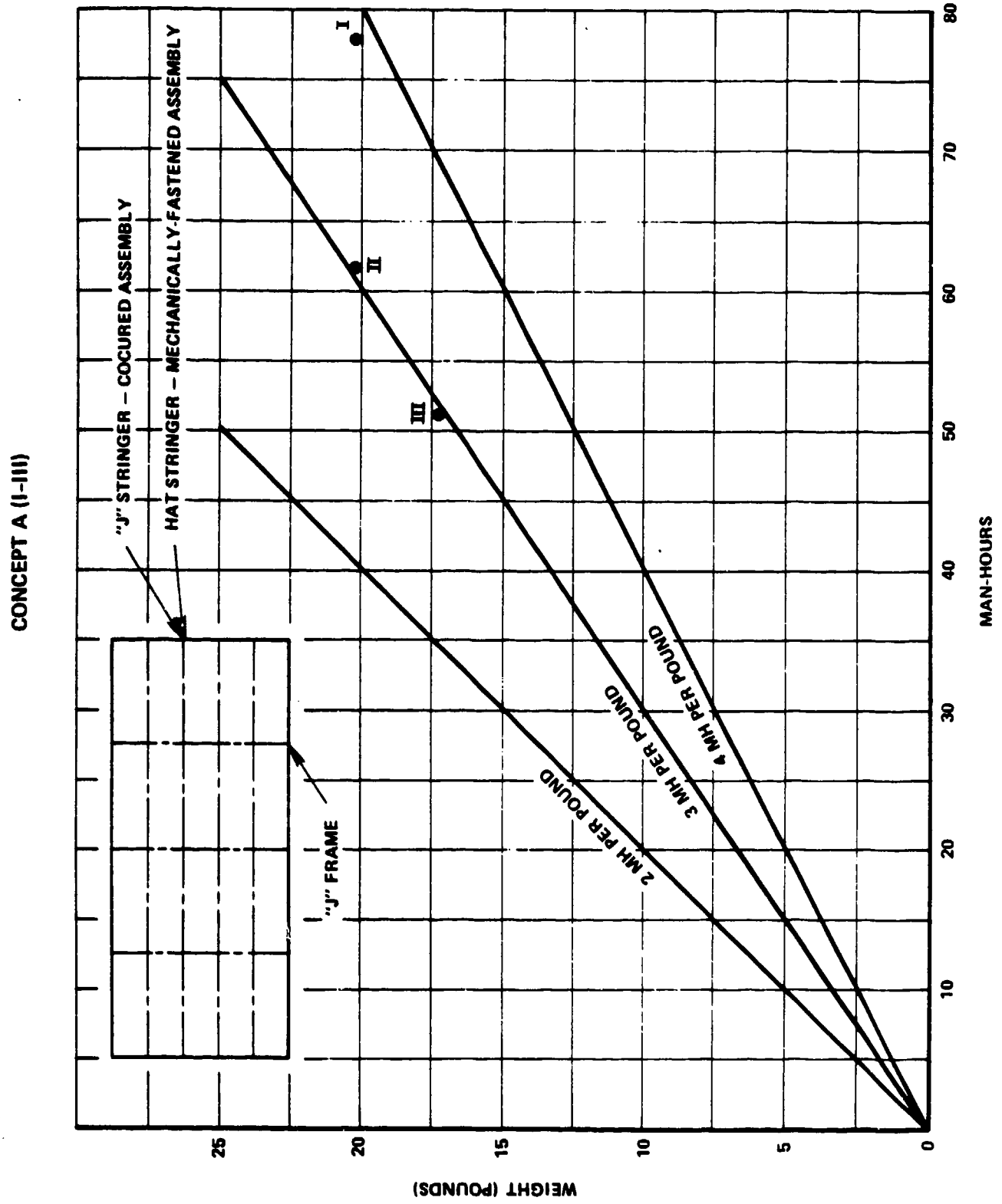



FIGURE 4.8-37. RESULTS FOR LIGHTWEIGHT/HIGH COMPLEXITY ADVANCED COMPOSITE CONCEPT

TABLE 4.8-15. MC/DG COST WORKSHEET

CONCEPT NO.: LIGHTWEIGHT / HIGH COMPLEXITY COCURED (A-III)

PAGE 1 of 2

| DESIGN CONCEPT | | RECURRING COST (RC) | | | | | | | | | NON-RECURRING COST (NRC) | | | PROGRAM COST | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L . LC . LR = LS + MS = RC . P/AC . DQ = PRC | | | | | | | | | NRC . LR = PNRC | | | 9 + 12 + DQ = COST/AC | | |
| PART NO. | DESCRIPTION | LABOR MC/DG MN/PT (1) | LC FACTOR (2) | LABOR RATE $/MH (3) | LABOR RC $/PT (4) | MAT'L $/PT (5) | REC. COST/ PT. $ (6) | PARTS PER AC (7) | DES. QTY. (8) | PROG. RC $ (9) | NRC MC/DG MN (10) | LABOR RATE $/MH (11) | PROG. NRC $ (12) | PROG. COST $ (13) | DES. QTY. (14) | COST/ AC $ (15) |
| 1 | SKIN | 9.13 | 1.30 | 25 | 296.73 | 256.96 | 553.69 | 1 | 200 | 110738 | 340 | 25 | 8500 | | | |
| 2 | STRINGERS | 4.83 | 1.30 | 25 | 156.98 | 39.60 | 196.58 | 4 | 200 | 157264 | 300 | 25 | 7500 | | | |
| 3 | FRAMES | 4.89 | 1.30 | 25 | 158.93 | 26.33 | 185.26 | 3 | 200 | 111156 | 255 | 25 | 6375 | | | |
| | | | | | | | | | | | | | | | | |
| | ASSEMBLY | 3.31 | 1.66 | 25 | 137.40 | — | 137.40 | 1 | 200 | 27480 | — | — | — | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | TOTALS | | | | | | | | | 406639 | | | 22375 | 429013 | 200 | 2145 |

BY: B. R. Nolan

DATE: FEB '82

TABLE 4.8-16. COST WORKSHEET - SUPPORTING DATA

CONCEPT NO. : LIGHTWEIGHT/HIGH COMPLEXITY COCURED (A-III)



| | |
|---|---|
| PART: SKIN<br>CED-G/E-7 & CED-G/E-8<br>8 PLY BASE 7.3 MH/PART × 0.84 FOR B STAGE = 6.13 TOOL 340 MH<br>6 LAYER STRIPPLIES-DICE-G/E-1<br>4-2" × 72" 1.44<br>3-2" × 36" 0.54<br>2-1" × 72" 0.40<br>2-1" × 36" 0.25<br>9.13 MAN-HOURS/PART | MATERIAL: BASE (36 × 72 × 8 × 0.0052) = 107.83<br>4(2 × 72 × 4 × 0.0052) = 11.98<br>3(2 × 36 × 4 × 0.0052) = 4.49<br>2(1 × 72 × 4 × 0.0052) = 3.00<br>2(1 × 36 × 4 × 0.0052) = 1.50<br>128.80 CU. IN.<br>128.80 CU. IN. × 0.057 LB/CU. IN. × 35 $/LB = $256.96 |
| PART: STRINGERS CED-G/E-3 & CED-G/E-4<br>7 IN. DEV. WIDTH 4.90 TOOL 300 MH<br>7 PLY BASE .84 - B STAGE<br>4.03 MAN-HOURS/PART<br>4 STRIPPLIES 1" WIDE 0.80 (4 × 0.20 EACH STRIP PLY)<br>(DICE-G/E-1) 4.83 MAN-HOURS/PART | MATERIAL: 7" × 72" × 7 × 0.0052 = 18.35<br>1 × 72 × 4 × 0.0052 = 1.50<br>19.85<br>19.85 CU. IN. × 0.057 LB/CU. IN. × 35 $/LB. = $39.60 |
| PART: FRAMES CED-G/E-3 & CED-G/E-4<br>7 PLY BASE PART 3.70 MAN-HOURS/PART × 0.84 FOR B STAGE = 3.11 TOOL 255 MH<br>4 PLY STRIP 1" WIDE 0.48 (4 × 0.12 EACH STRIPPLY)<br>(DICE-G/E-1)<br>CUTOUTS (4) 0.26 (4 × 0.065)<br>(DICE-G/E-1)<br>DOUBLERS 1.04 (4 × 2 × .013)<br>(DICE-G/E-4) 4.89 MAN-HOURS/PART | MATERIAL: 9.5 × 36 × 7 × 0.0052 = 12.45<br>1 × 36 × 4 × 0.0052 = 0.75<br>13.20<br>13.20 CU. IN. × 0.057 LB/CU. IN. × 35 $/LB. = $26.33 |
| ASSEMBLY: COCURING<br>CED-G/E-10<br>HANDLING, ETC. 0.67<br>BAGGING, ETC. 2.64<br>3.31 MAN-HOURS/ASSEMBLY | ASSEMBLY: |

TABLE 4.8-17. INSTRUCTIONS TO UTILIZE DESIGNER'S WORKSHEET

| Step No. | Worksheet Column | Input | Procedure |
|---|---|---|---|
| 1 | | Part no. | Enter identification, if available. |
| 2 | | Description | Enter brief description, e.g., Stiffener, Zee, J section, etc. |
| 3 | 1 | Manufacturing Labor | From CED section determine man-hours per part at 200 units. |
| 4 | 2 | Learning curve (LC) factor | Based upon learning curve percentage and design quantity. Factor provided by user company. |
| 5 | 3 | TI&E labor | From MC/DG, enter RC for TI&E (man-hours). |
| 6 | 4 | Labor rate | Current manufacturing labor rate including direct labor fringe benefits and overhead charges. |
| 7 | 5 | Labor recurring costs (RC) | Product of Column 1 times Column 2 plus Column 3 times Column 4. |
| 8 | 6 | Material cost | Based upon furnished data in company utilizing MC/DG, enter material cost per part in dollars. |
| 9 | 7 | Recurring cost (RC) per part | Total of Columns 5 and 6. |
| 10 | 8 | Parts per aircraft | Number of identical parts per aircraft. |
| 11 | 9 | Design quantity | Number of aircraft in buy considered. |
| 12 | 10 | Program recurring cost (RC) | Product of Column 7 times Column 8 times Column 9. |
| 13 | 11 | Nonrecurring tooling cost (NRTC) | From MC/DG, enter NRTC in man-hours. |
| 14 | 12 | NRTC for TI&E | From MC/DG, enter NRTC for TI&E in man-hours. |
| 15 | 13 | Labor rate | See Column 3. |
| 16 | 14 | Program nonrecurring tooling costs (NRTC) | Columns 11 plus 12 times Column 13. |
| 17 | 15 | Program cost | Sum of Column 10 and Column 14. |
| 18 | 16 | Design quantity | See Column 9. |
| 19 | 17 | Cost per aircraft | Column 15 divided by Column 16. |

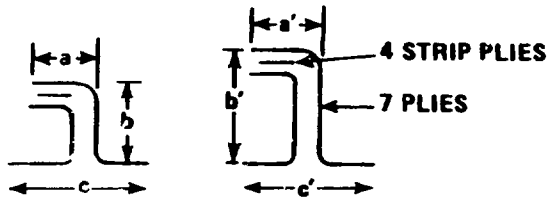
TABLE 4.8-18. TRADE-OFF STUDY ON ADVANCED COMPOSITE FUSELAGE PANEL

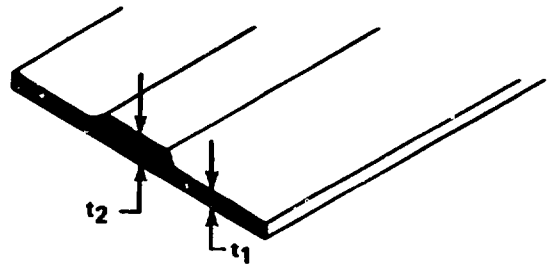
Formats Utilized for Integrated Example

| Concept | Cost Item | Format Number |
|---|---|---|
| Lightweight/High Complexity Mechanically Fastened (Concepts A-I and A-II) | Skin | CED-G/E-7 and CED-G/E-8 |
| | Hat Stringers | CED-G/E-1 and CED-G/E-2 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cutouts | DICE-G/E-2 |
| | Cutout Doublers | DICE-G/E-4 |
| | Assembly (Mechanical) | CED-MFA-2 and CED-MFA-3 |
| Lightweight/High Complexity Cocured (Baseline Concept A-III) | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Stringers | CED-G/E-3 and CED-G/E-4 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cutouts | DICE-G/E-2 |
| | Cutout Doublers | DICE-G/E-4 |
| | Assembly (Cocured) | CED-G/E-10 |
| Moderate Weight/ Moderate Complexity 4 Stringers/3 Frames (Concept B) | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Stringers | CED-G/E-3 and CED-G/E-4 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cutouts | DICE-G/E-2 |
| | Cutout Doublers | DICE-G/E-4 |
| | Assembly (Cocured) | CED-G/E-10 |
| Moderate Weight/ Moderate Complexity 3 Stringers/3 Frames (Concept C) | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Stringers | CED-G/E-3 and CED-G/E-4 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cutouts | DICE-G/E-2 |
| | Cutout Doublers | DICE-G/E-4 |
| | Assembly (Cocured) | CED-G/E-10 |
| Minimum Part Count (Concept D) | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Assembly (Cocured) | CED-G/E-10 |

TABLE 4.8-19. SUMMARY OF MANUFACTURING COST (MAN-HOURS) AND WEIGHT OF COMPOSITE CONFIGURATIONS

DIMENSIONS IN INCHES




| CONFIGURATION | | STRINGERS | | | | FRAMES | | | | SKIN | | *MAN-HOURS | WEIGHT, LB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NUMBER | a | b | c | NUMBER | a' | b' | c' | $t_1$ | $t_2$ | | |
| A-III | BASELINE-LIGHT WEIGHT/ HIGH COMPLEXITY COCURED | 4 | 1.00 | 1.50 | 2.00 | 3 | .75 | 3.00 | 2.00 | 8 PLY | 12 PLY | 51.10 | 17.45 |
| B | MODERATE WEIGHT/ MODERATE COMPLEXITY | 4 | .50 | 1.40 | 2.00 | 3 | .75 | 2.80 | 2.00 | 12 PLY | 12 PLY | 49.20 | 17.65 |
| C | MODERATE WEIGHT/ MODERATE COMPLEXITY | 3 | 1.00 | 1.60 | 2.00 | 3 | .75 | 3.20 | 2.00 | 12 PLY | 12 PLY | 48.04 | 18.80 |
| D | LOW COMPLEXITY | 0 | 0 | 0 | 0 | 3 | .75 | 3.00 | 2.00 | 24 PLY | 24 PLY | 34.79 | 22.50 |

$$*\text{RECURRING} + \frac{\text{NON-RECURRING}}{200}$$

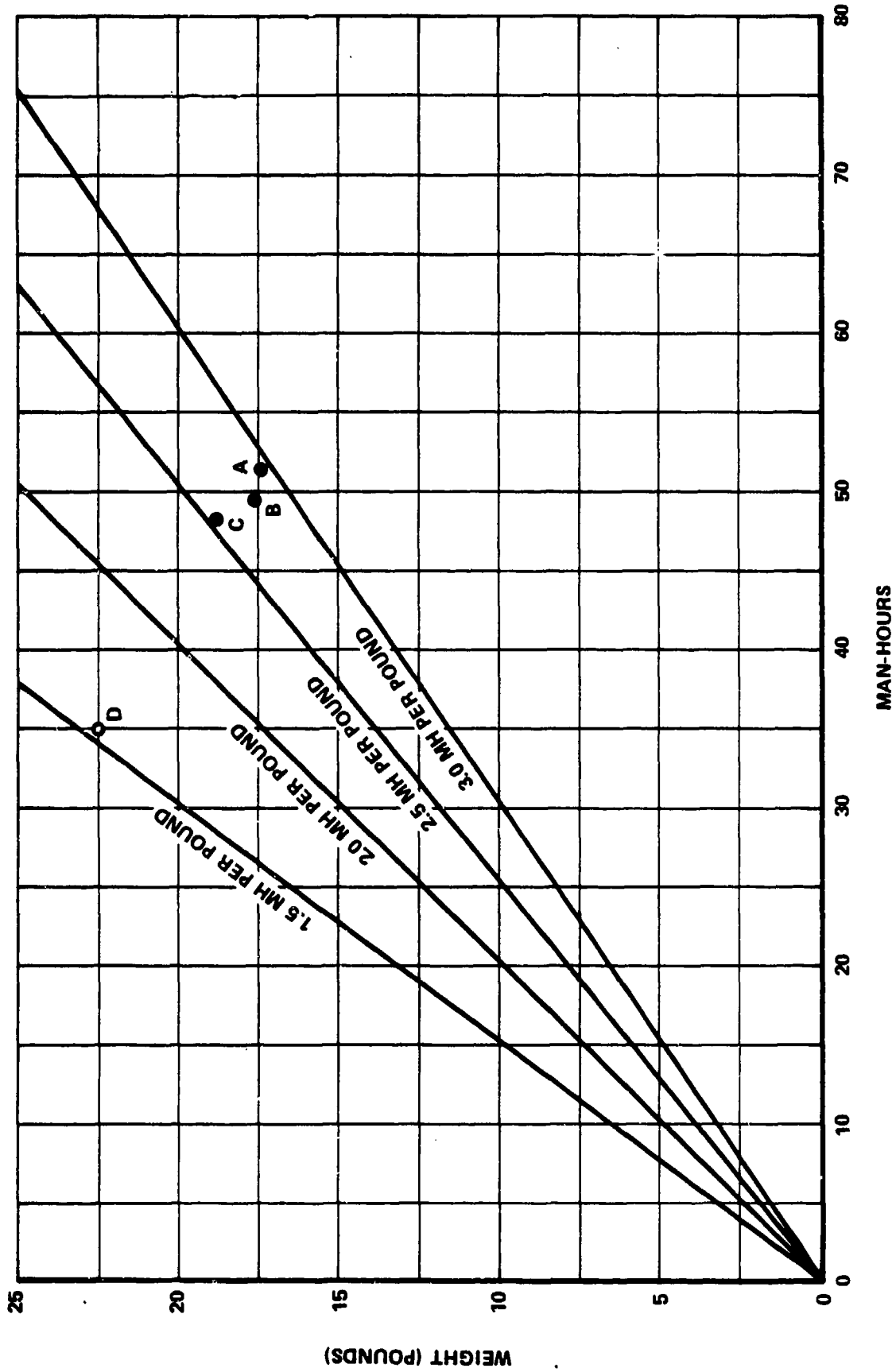
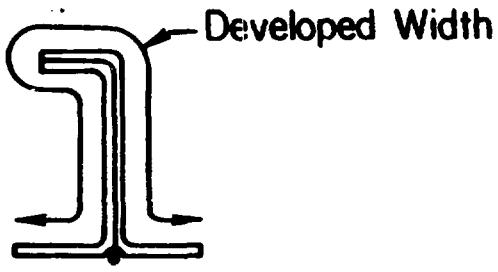
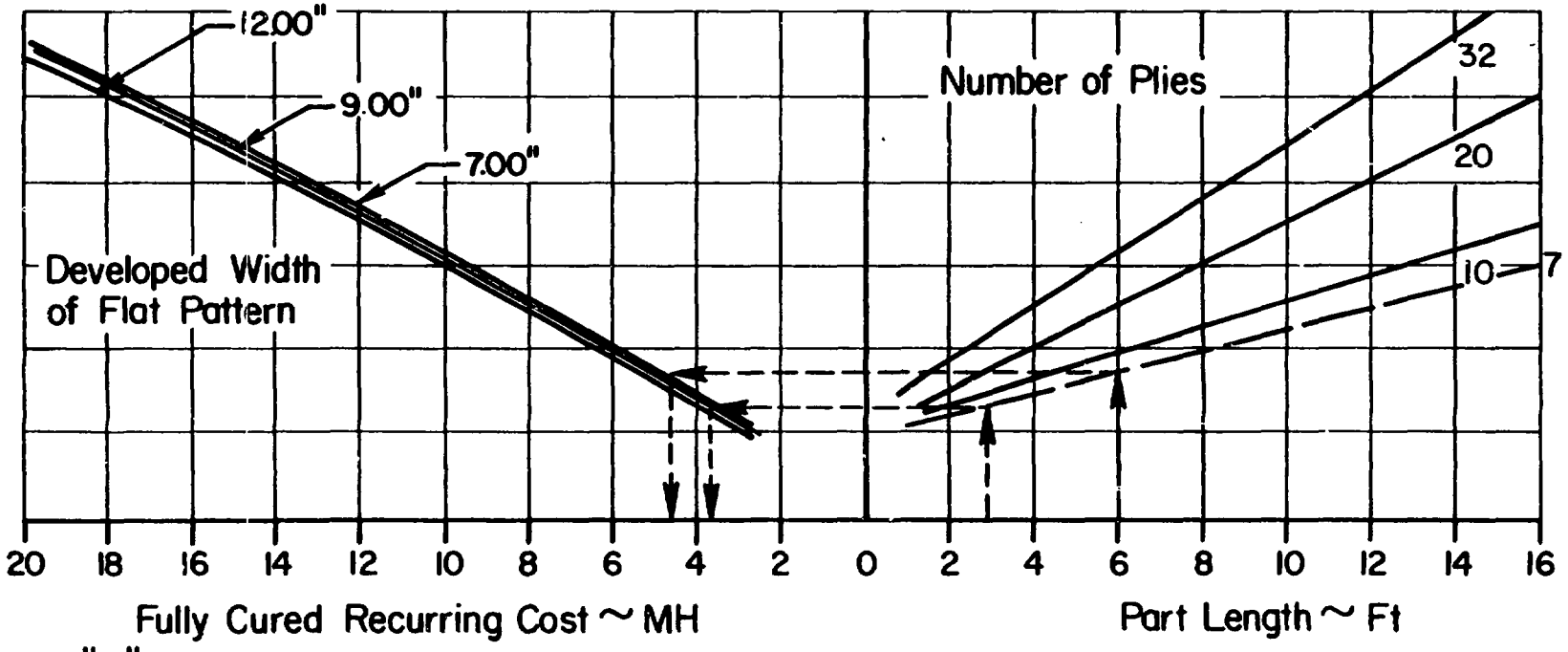



FIGURE 4.8-38. SUMMARY OF RESULTS IN ADVANCED COMPOSITE FUSELAGE SHEAR-PANEL TRADE-OFF STUDY

# COMPOSITE J SECTION RECURRING COST/PART

Influenced By
- Part Length
- Number of Plies
- Developed Flat Pattern Width
- Cure Stage



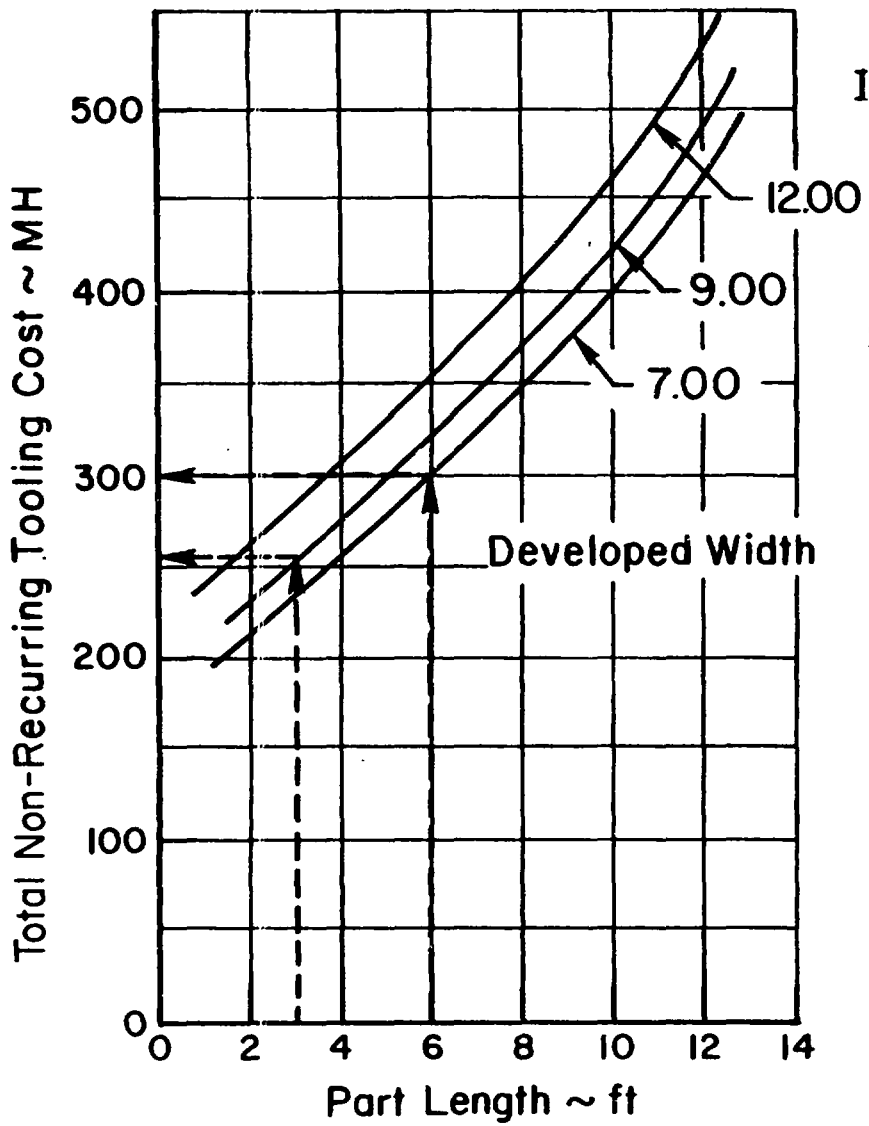

For "B" Stage Recurring Cost, Multiply by 0.84

See Ground Rules for Limitations and Considerations

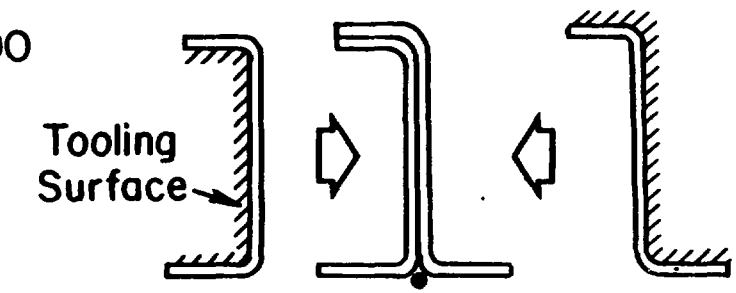
CED-G/E-3

FIGURE 4.8-39. FORMAT USED IN TRADE-OFF STUDY

## COMPOSITE J SECTION TOTAL NON-RECURRING TOOLING COST/PART




Influenced by { • Part Length • Developed Width }




See Ground Rules for Limitations and Considerations

CED-G/E-4

FTR450261000U
3 Jan 1983

FIGURE 4.8-40. FORMAT USED IN TRADE-OFF STUDY

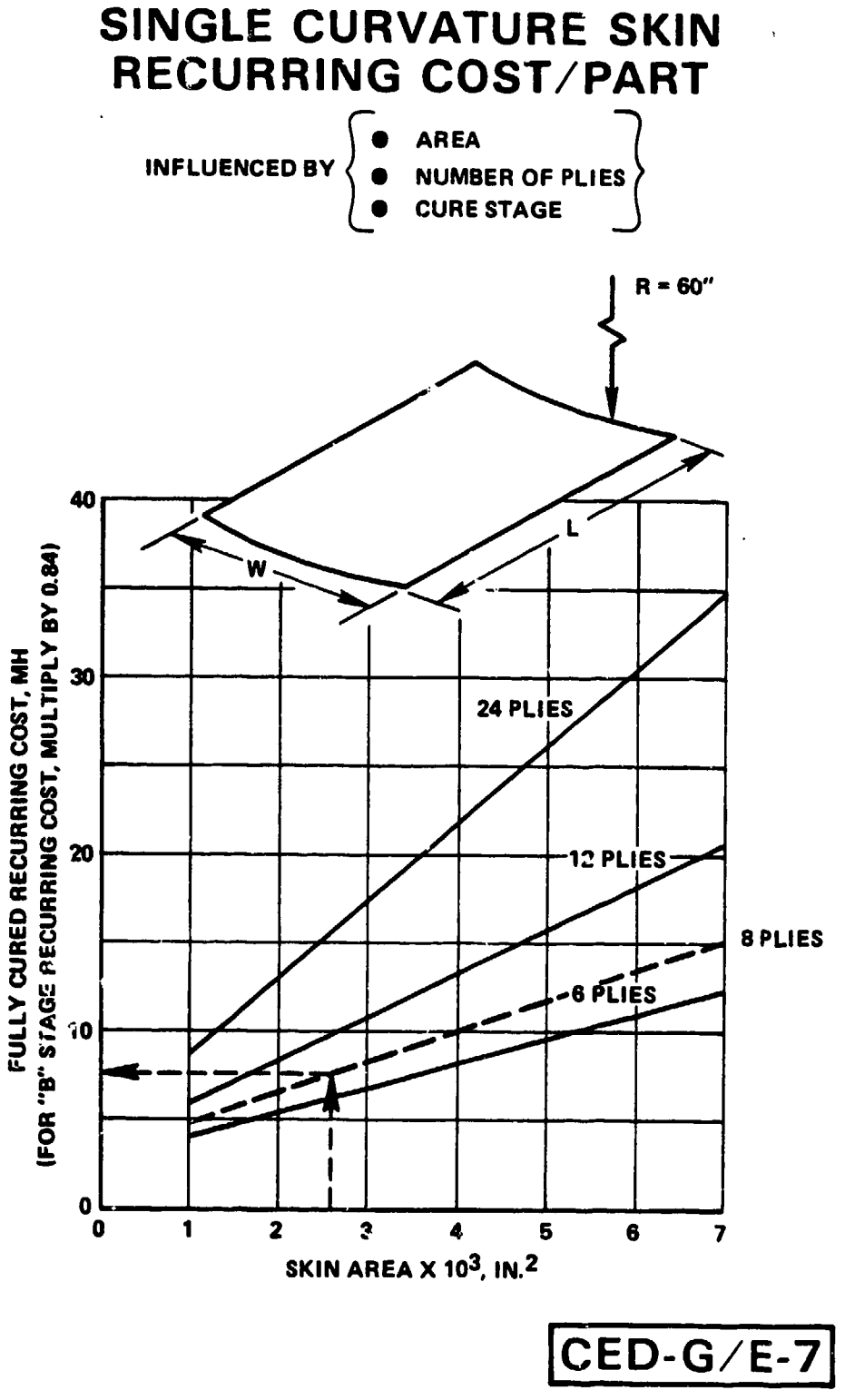
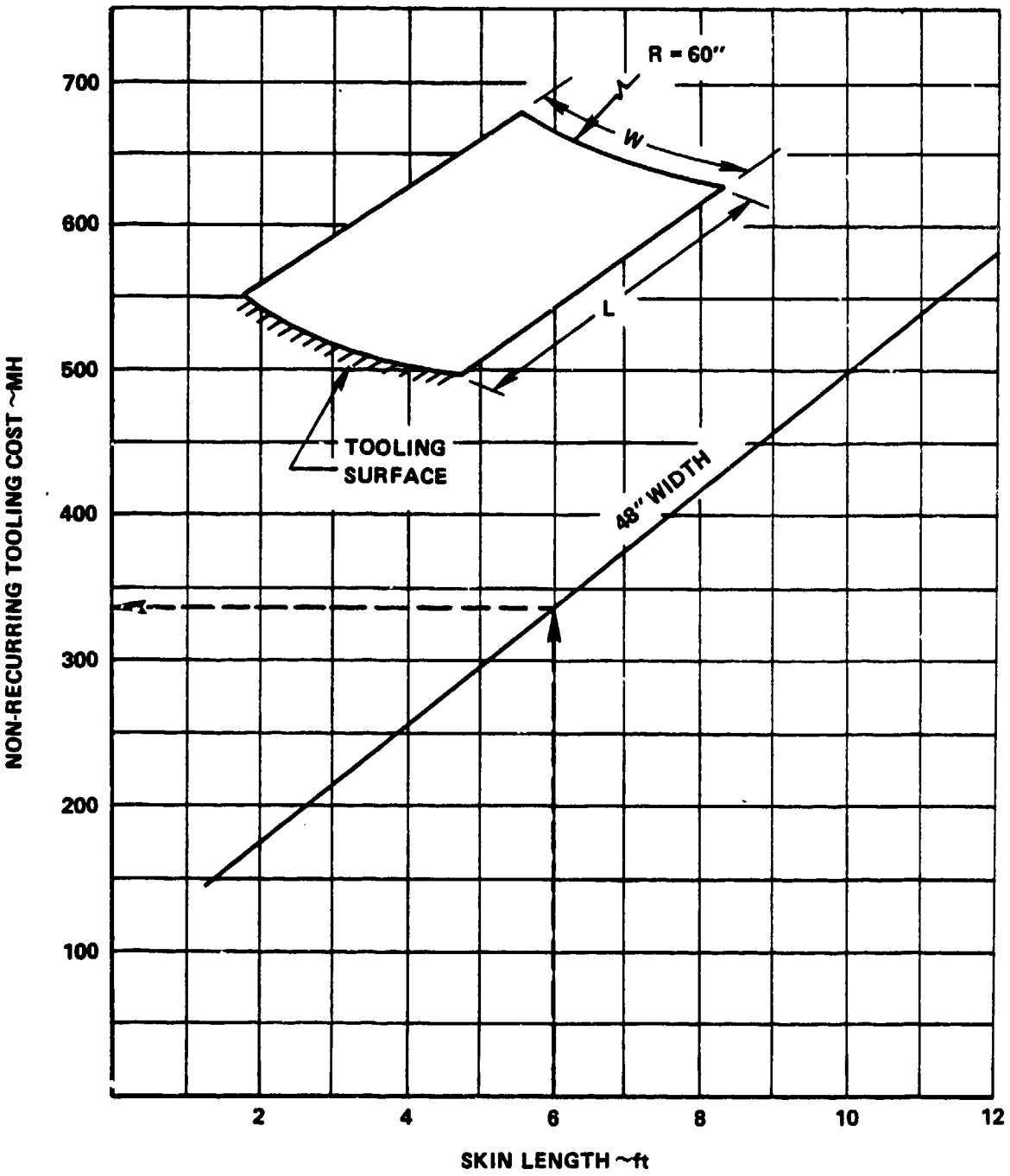



FIGURE 4.8-41. FORMAT USED IN TRADE-OFF STUDY

# SINGLE CURVATURE SKIN NON-RECURRING TOOLING COST/PART

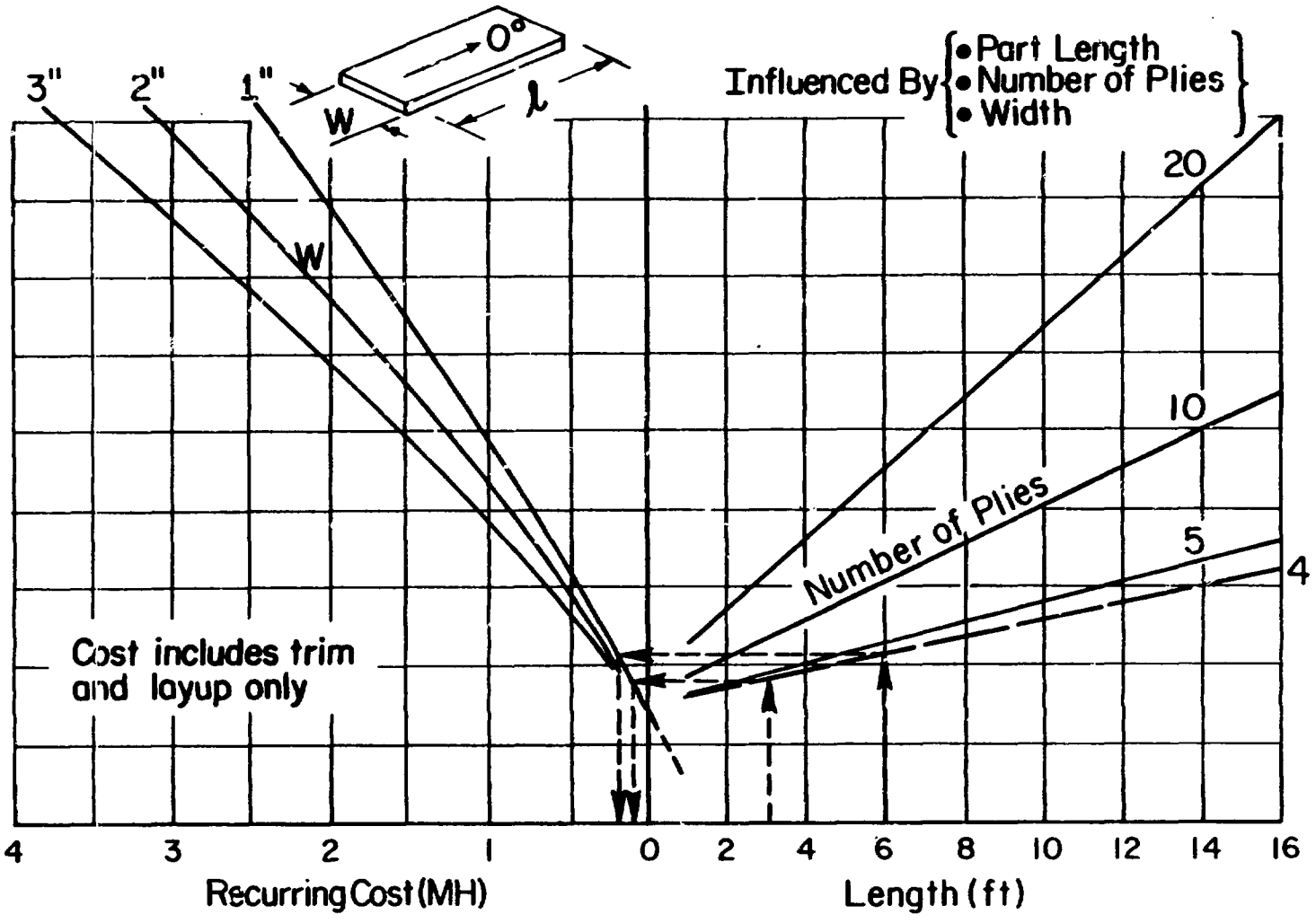



SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

FIGURE 4.8-42. FORMAT USED IN TRADE-OFF STUDY

CED-G/E-8

# STRIP PLIES (FLAT PARTS) FOR COCURING RECURRING COST/PART




SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-1

Strip plies for frames and stringers
are shown on this page.

FIGURE 4.8-43. FORMAT USED IN TRADE-OFF STUDY

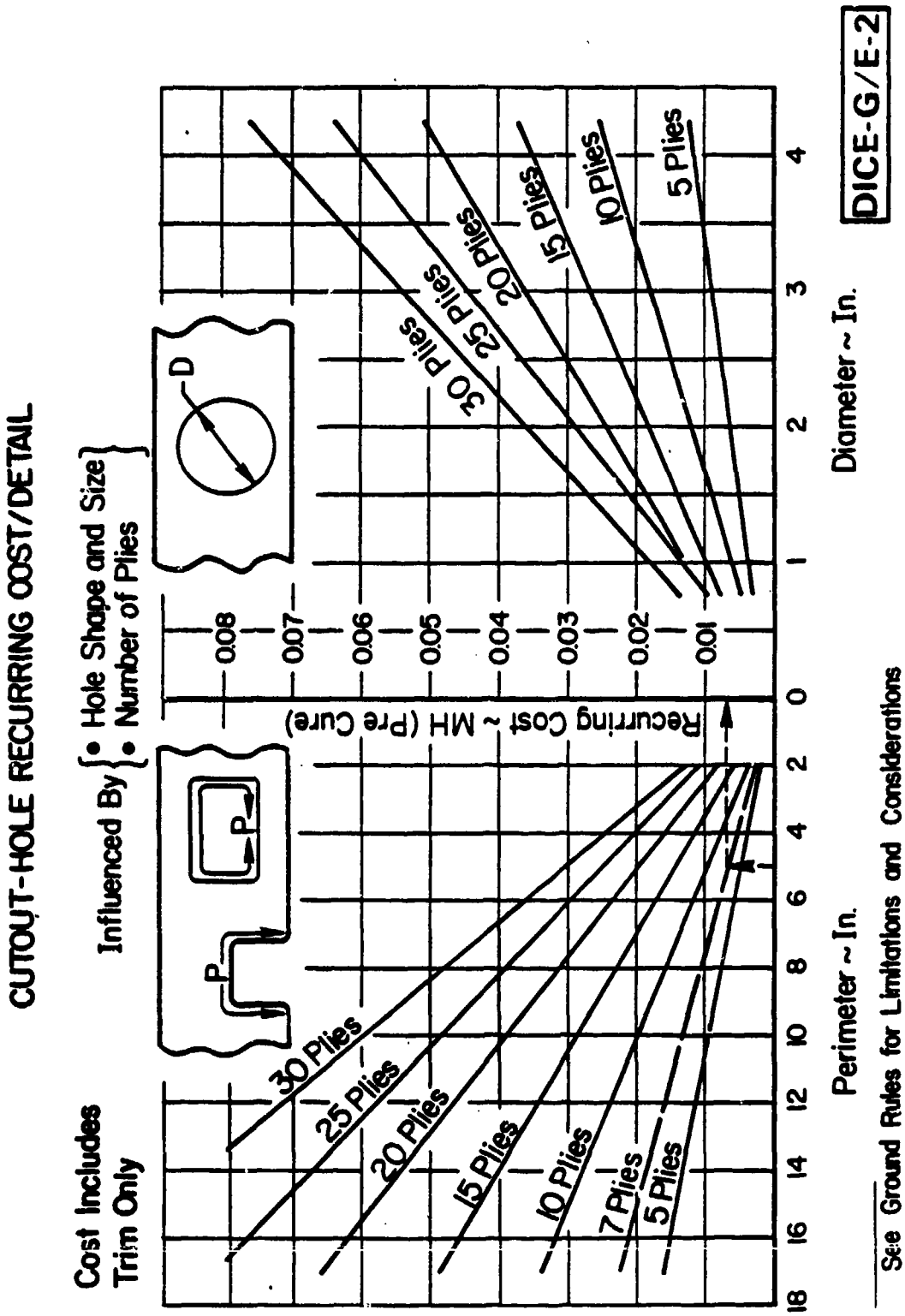
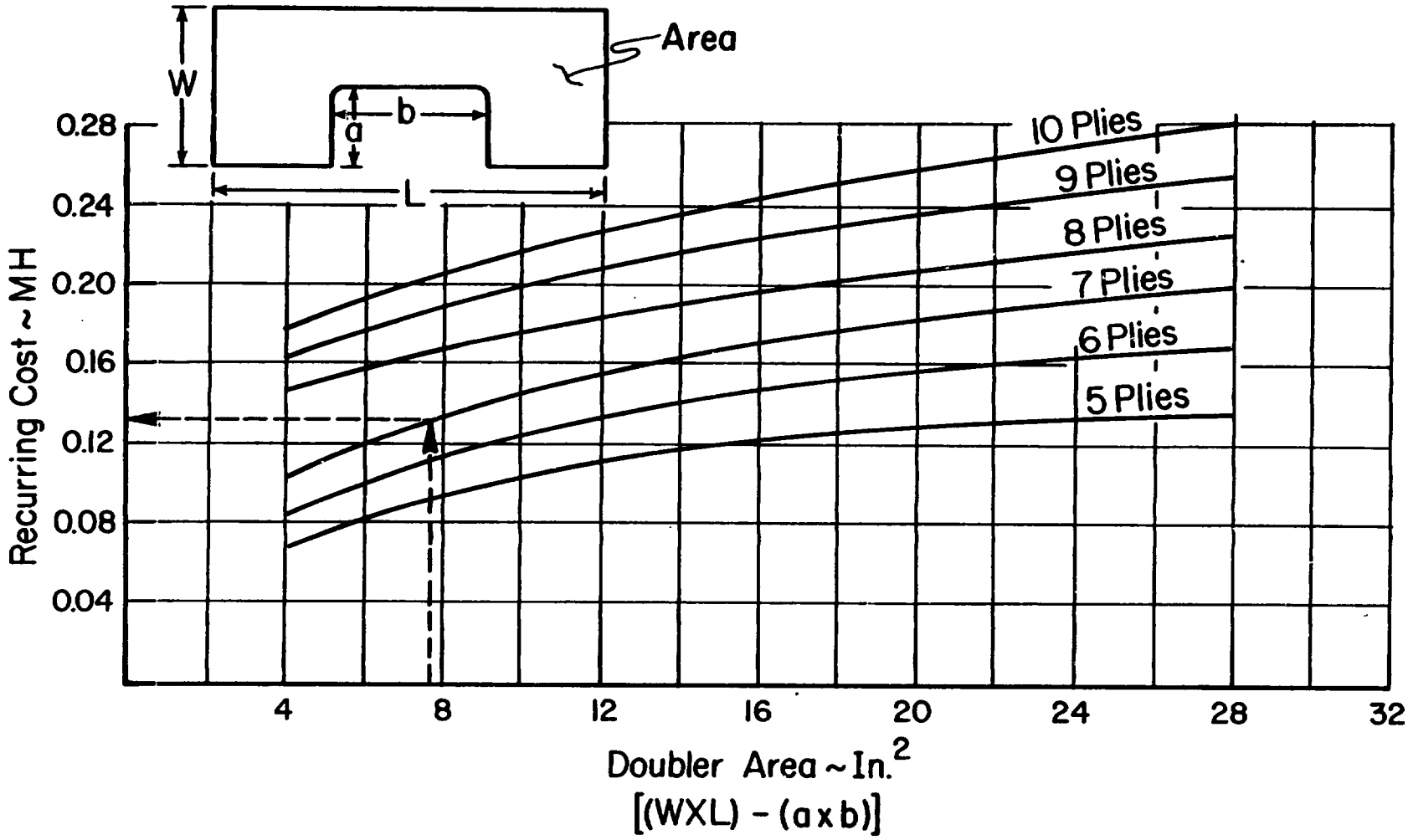



FIGURE 4.8-44. FORMAT USED IN TRADE-OFF STUDY

# CUTOUT REINFORCING DOUBLER FOR COCURING: RECURRING COST/DETAIL

Influenced By { • Area • Number of Plies }

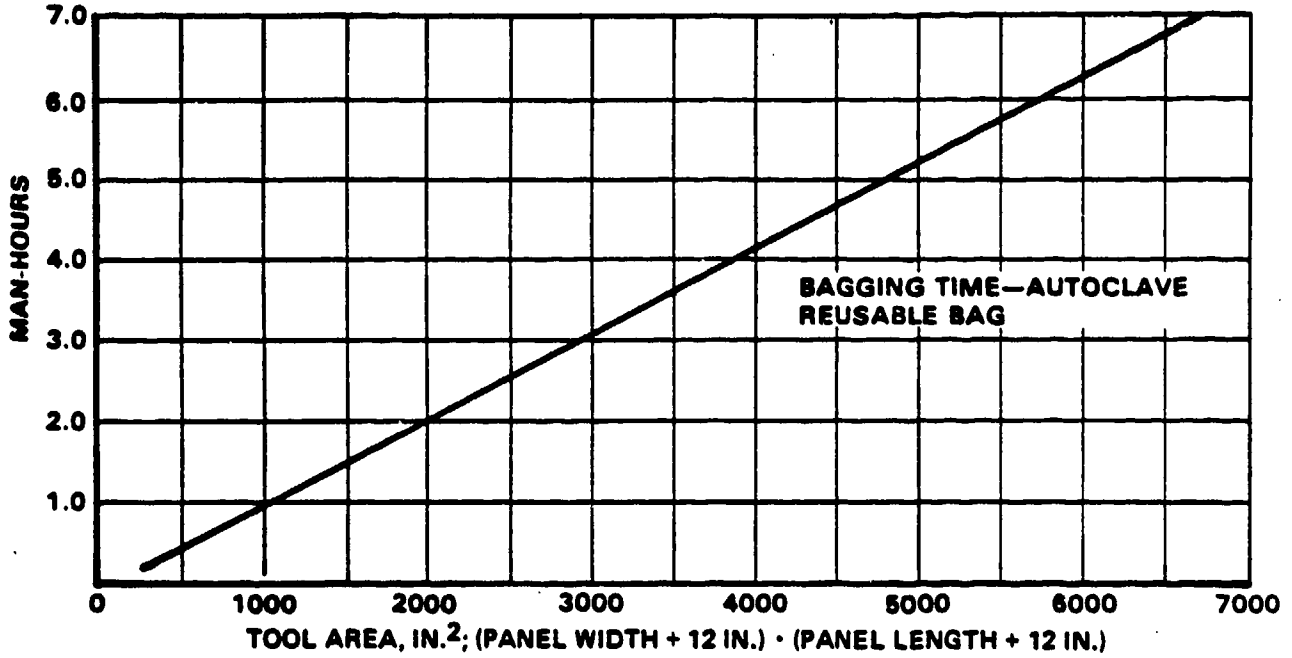


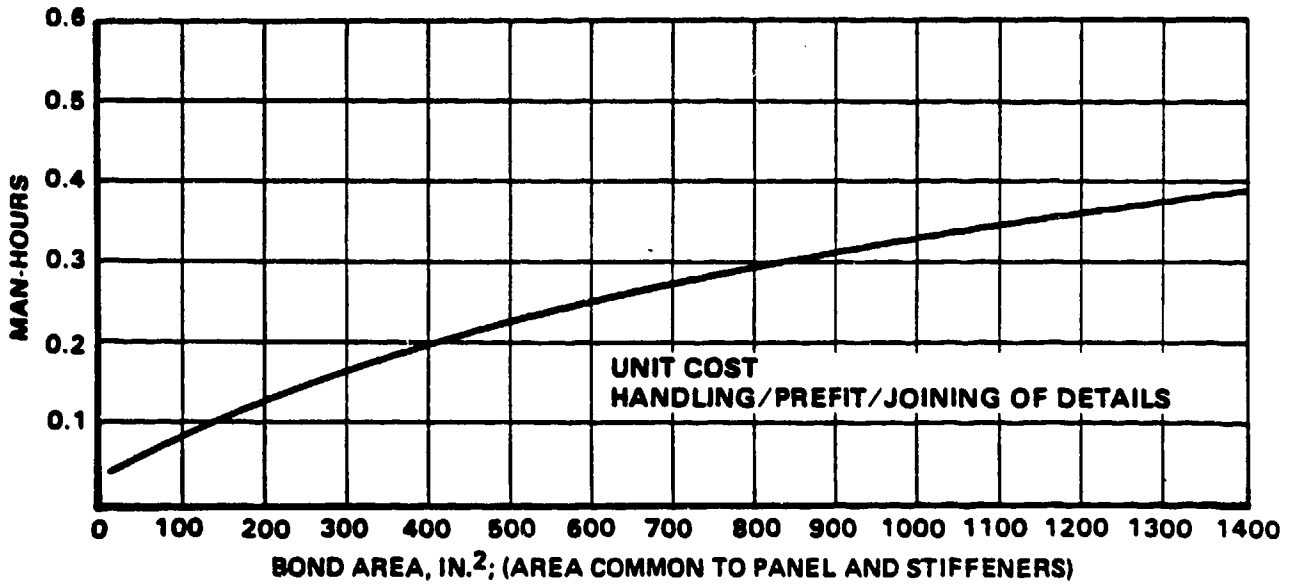

SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-4

FIGURE 4.8-45. FORMAT USED IN TRADE-OFF STUDY

# ASSEMBLY TIME




Notes: (1) To determine recurring cost of assembly and bond of fully cured skin and stiffener details, use both CED-G/E-10 formats and both CED-G/E-9 formats.

(2) Tool made for panel (CED-G/E-8) also used for these operations.

CED-G/E-10

FIGURE 4.8-46. FORMAT USED IN TRADE-OFF STUDY

## 4.9 Supplementary Forms

### 4.9.1 Worksheets for Designer Use

To conveniently utilize the manufacturing man-hour data presented in the MC/DG, Designer Worksheets have been prepared. These have also been utilized for various examples for discrete parts and sub-assemblies in the MC/DG sections and also for the integrated examples on aluminum, titanium, and composite fuselage panels (Volume III of the User's Manual FTR450261000U).

While the use of the Designer Worksheets is optional, a blank copy of each is included here for the convenience of those that prefer this approach and would like to reproduce a supply. The worksheets are as follows:

- MC/DG Cost Worksheet
- Extrusion Cost Worksheet
- Casting Cost Worksheet
- Casting Machining Cost Worksheet
- Forging Cost Worksheet
- Machining Cost Worksheet for Forgings.

### 4.9.2 Document Request Order Form

The documents available on the Air Force ICAM "Manufacturing Cost/ Design Guide" project are listed on the Request Order Form provided at the conclusion of this section. Documents generated under the contract contain controlled distribution and export control clauses.

# MC/DG COST WORKSHEET

PAGE ____ ____

| DESIGN CONCEPT | | RECURRING COST (RC) | | | | | | | | | | NON-RECURRING COST (NRC) | | | | PROGRAM COST | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (L . LC + TI&E) LR = L$ + M$ = RC . P/AC . DQ = PRC | | | | | | | | | | (NRC + TI&E) LR = PNRC | | | | 10 + 14 + DQ = COST/AC | | |
| PART NO. | DESCRIPTION | LABOR MC/DG MH/PT (1) | LC FACTOR (2) | LABOR TI&E MH/PT (3) | LABOR RATE $/MH (4) | LABOR RC $/PT (5) | MAT'L $/PT (6) | REC. COST/ PT. $ (7) | PARTS PER AC (8) | DES. QTY. (9) | PROG. RC $ (10) | NRC MC/DG MH (11) | NRC TI&E MH (12) | LABOR RATE $/MH (13) | PROG. NRC $ (14) | PROG. COST $ (15) | DES. QTY. (16) | COST/ AC $ (17) |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | TOTALS | | | | | | | | | | | | | | | | | |

REMARKS _____

BY: _____

DATE: _____



FTR450261000U
3 Jan 1983

# EXTRUSIONS-COST WORKSHEET

**PART NO.:** **DESCRIPTION:** **DESIGNER:** **DATE:**

**MATERIAL COST***

_____ Sq in. (Cross Section Area) x _____ Lb/in.$^3$ (Density) = _____ Lb/Ft (Weight)

Base Price (CED-EXTN- _____ ) $ _____ /Lb

**ALUMINUM ONLY:**

_____ in./ (Perimeter) _____ Lb/Ft (Weight) = _____ (Factor)

Alloy/Temper Multiplier (CED-EXTN-2) _____

_____ (Dec. Qty.) x _____ (Parts/Airplane) = _____ (Total Qty.) ; Setup Cost (CED-EXTN-3) - $ _____ /Part

_____ (Mat'l/Part) = _____ Ft (Length†) x _____ Lb/Ft (Weight) x $ _____ /Lb (Base Price) x _____ *Multiplier + $ _____ Ea. (Setup) _____ **Inflation $ _____ (a)

Nonrecurring Extrusion Die Cost (CED-EXTN- _____ ) $ _____ (b)

*Aluminum Only **Inflation Factor to be Supplied by User Company

| FABRICATION COST | FORMAT NUMBER | RECURRING COST | NONRECURRING COST |
|---|---|---|---|
| BASE PART COST _____ | CED-EXTN- | MH | MH |
| DICE - _____ | DICE-EXTN- | MH | MH |
| DICE - _____ | DICE-EXTN- | MH | MH |
| Test, Inspection & Evaluation _____ | CED- | MH | MH |
| TOTAL FABRICATION COST (UNIT 200) | | (c) MH | (d) MH |
| (e) Learning Curve Factor—See Table Below | | | |
| (f) Labor Rate | | $ /MH | $ MH |
| (g) Fabrication Cost—Recurring/Part(c x e x f) | | $ EA | |
| (h) Fabrication Cost—Nonrecurring(d x f) | | | $ |

**COST SUMMARY**

| | |
|---|---|
| (a) Material Cost/Part | $ |
| (g) Fabrication Recurring Cost/Part | $ |
| (i) Design Quantity | |
| (j) Program Recurring Cost (a + g) i | $ |
| (b) Nonrecurring Cost—Material | $ |
| (h) Nonrecurring Cost—Fabrication | $ |
| (k) Nonrecurring Cost—Total (b + h) | $ |
| (m) Program Cost (j + k) | $ |
| (n) Cost/Part (m ÷ i) | $ |

†Length of extrusion required for curved (stretch formed) parts is part length + 2 feet.

| Dec. Qty | LC Factor | Dec. Qty | LC Factor |
|---|---|---|---|
| 1 | 2.25 | 200 | 1.17 |
| 10 | 1.79 | 300 | 1.06 |
| 25 | 1.59 | 500 | 1.02 |
| 50 | 1.44 | 750 | 0.96 |
| 100 | 1.30 | 1000 | 0.92 |

90% Learning Curve Factor to Convert Unit 200 Format cost to Cumulative Average cost for Various Design Quantities.

# CASTING COST WORKSHEET

**PREPARED BY:** **DATE:**

| | |
|---|---|
| **PART TITLE** _____ | **DESIGN QUANTITY** _____<br>**LOT QUANTITY** _____ |

| **MATERIAL** | **SPECIFICATION** | **FOUNDRY PROCESS** |
|---|---|---|
| **Aluminum** | | |
| **356** _____ | **QQ-A-601** _____ | |
| **A356** _____ | **MIL-A-21180** _____ | **Sand** _____ |
| **Steel** | **AMS 4218** _____ | **Investment** _____ |
| **17-4 PH** _____ | **AMS 5355** _____ | |

**BOX VOLUME = W x L x T**

| **ITEM** | | |
|---|---|---|
| **RECURRING COST** | | |
| a) Base Cast Cost | (Ref _____) | $ _____ |
| b) DICE Factor | (Ref _____) | _____ |
| c) Lot Quantity Factor | (Ref _____) | _____ |
| d) Test Insp. & Eval. Cost | (Ref _____) | $ _____ |
| e) Inflation Factor | | _____ |
| f) Recurring Cost (a x b x c + d)e | | $ _____ |
| **NONRECURRING COST** | | |
| g) Base Nonrecurring Cost | (Ref _____) | $ _____ |
| h) N R DICE Factor | (Ref _____) | _____ |
| i) Check Fixtures | (Ref _____) | $ _____ |
| j) Static Test Cost | (Ref _____) | $ _____ |
| e) Inflation Factor | | _____ |
| k) Nonrecurring Cost = (g x h + i + j)e | | $ _____ |
| **COST SUMMARY** | | |
| f) Recurring Cost/Part | | $ _____ |
| l) Machining Cost/Part | | $ _____ |
| m) Design Quantity | | _____ |
| n) Program Recurring Cost (f + l)m | | $ _____ |
| k) Nonrecurring Cost | | $ _____ |
| o) Program Total Cost (n + k) | | $ _____ |
| p) Total Cost/Part (o ÷ m) | | $ _____ |

# CASTING MACHINING COST WORKSHEET

| MACHINING FEATURE | FORMAT | RECURRING COST | NONRECURRING COST |
|---|---|---|---|
| Holes - No. _____ Size _____<br>Drill<br>Drill & Spotface<br>Drill & Ream<br>Cost Per Part | | MH | MH |
| Flange Facing<br>Mean Diam _____ Width _____<br>Cost Per Part | | MH | MH |
| Face Milling<br>Area Milled _____ Sq. In.<br>Cost Per Part | | MH | MH |
| Face & Counterbore Hub<br>Ctrbore Diam _____ No. _____<br>Cost Per Part | | MH | MH |
| Clevis-Str. Mill/Drill/Ream<br>No. _____ Size _____<br>Cost Per Part | | MH | MH |
| Machining Cost (Unit 200) Per Part | | MH | MH |
| Learning Curve Factor<br>Labor Rate<br>Machining Cost/Part*<br>Nonrecurring Cost | | _____<br>$ _____ /HR<br>$ _____ | <br>$ _____ /HR<br><br>$ _____ |

*Machining cost/part = U200 cost/part x LC factor x labor rate.

| Des. Qty | LC Factor | Des. Qty | LC Factor |
|---|---|---|---|
| 1 | 2.25 | 200 | 1.17 |
| 10 | 1.79 | 350 | 1.08 |
| 25 | 1.59 | 500 | 1.02 |
| 50 | 1.44 | 750 | 0.96 |
| 100 | 1.30 | 1000 | 0.92 |

90% Learning Curve Factor to Convert Unit 200 Format Cost to Cumulative Average Cost for Various Design Quantity.

# FORGING COST WORKSHEET

TITLE: DESIGN QUANTITY: LOT QUANTITY: DESIGNER: DATE:

| TYPE | MATERIAL | HAND/RING | BLOCKER/CONV. | CONV. /PRECISION | PRECISION | TEST, INSP. & EVALUATION |
|---|---|---|---|---|---|---|
| Hand ____<br>Ring ____<br>Blocker ____<br>Conv. ____<br>Precision ____ | Aluminum ____<br>TiGAl-4V ____<br>4340<br>Air ____<br>Vacuum ____<br>PH Cres<br>15-5 ____<br>13-8 ____ | Size<br>L ____ OD ____<br>W ____ ID ____<br>T ____ T ____<br>Weight ____ Lb<br>Base Cost<br>$ ____ /Lb | Weight ____ Lb<br>Base Cost<br>$ ____ /Lb<br>Setup Cost<br>$ ____ /Lot<br>Size L ____<br>W ____ H ____<br>Die Factor ____ | Category<br>A ____ B ____<br>C ____ D ____<br>Plan Area<br>____ Sq. in.<br>Buy-Quantity<br>Factor ____ | Base Cost<br>$ ____ Ea.<br>Setup Cost<br>$ ____ Ea.<br>DICE Factor<br>Rec. ____<br>Nonrec. ____ | First Article Cost<br>One Forging + $ ____ = $ ____<br>Production Cost/Lot<br>One Forging + $300 = $ ____<br>Ultrasonic Insp. $ ____ Each<br>Inflation Factor ____ |

## RECURRING COST

### Hand/Ring Forging

Cost/Part = Weight x Base Cost x Inflation Factor

= ____ Lbs x $ ____ /Lb x ____ = $ ____ Each

### Blocker Forging

$$\text{Cost/Part} = \left[\text{Weight} \times \text{Base Cost} \times 0.8 \times \frac{\text{Buy Qty. Factor}}{} + \frac{\text{Setup/Lot}}{\text{Buy Qty.}}\right] \text{Inflation Factor}$$

$$= \left[____ \text{Lb} \times \$____ /\text{Lb} \times 0.8 \times ____ + \frac{\$____}{(\quad)} /\text{Lot}\right] ____$$

= $ ____ Each

### Conventional Forging

$$\text{Cost/Part} = \left[\text{Weight} \times \text{Base Cost} \times \frac{\text{Buy Qty. Factor}}{} + \frac{\text{Setup/Lot}}{\text{Buy Qty.}}\right] \text{Inflation Factor}$$

$$= \left[____ \text{Lb} \times \$____ \text{Lb} \times ____ + \frac{\$____}{(\quad)} /\text{Lot}\right] ____$$

= $ ____ Each

### Precision Forging

$$\text{Cost/Part} = \left[\text{Base Cost} \times \frac{\text{Rec. DICE Factor}}{} \times \frac{\text{Buy Qty. Factor}}{} + \text{Setup}\right] \text{Inflation Factor}$$

$$= \$\left[____ \text{Each} \times ____ \times ____ + \$____ \text{Each}\right] ____$$

= $ ____ Each

## NONRECURRING COST

### Blocker / Conventional Forging

$$\text{Tool Cost} = (L + 12")(W + 12")(H + 14") \frac{\text{Die}}{\text{Factor}} \times \frac{\text{Inflation}}{\text{Factor}}$$

= ( ____ +12") x ( ____ +12") x ( ____ +14") x ____ x ____

= $ ____

### Precision Forging

$$\text{Tool Cost} = \text{Base Tool Cost} \times \frac{\text{Nonrec. DICE}}{\text{Factor}} \times \frac{\text{Inflation}}{\text{Factor}}$$

= ____ x ____ x ____

= $ ____

## Cost Summary

$$\text{Program Cost} = \text{Cost/Part} \times \frac{\text{Design}}{\text{Quantity}} + \text{Tool Cost} + \frac{\text{First Article}}{\text{T\&E Cost}} + \frac{\text{Prod T\&E}}{\text{Cost/Lot}} \times \frac{\text{Design Qty.}}{\text{Lot Qty.}}$$

$$= \$____ \times ____ + \$____ + \$____ + \$____ \times \frac{(\quad)}{(\quad)}$$

$$= \$____ \text{Total Cost/Part} = \frac{\text{Program Cost}}{\text{Design Qty.}} = \$____ \text{Each}$$

# MACHINING COST WORKSHEET FOR FORGINGS

| MACHINING FEATURE | FORMAT | RECURRING COST (MAN-HOURS) | NONRECURRING TOOLING COST (MAN-HOURS) |
|---|---|---|---|
| HOLES: NO. _____ SIZE _____<br>DRILL<br>DRILL & SPOTFACE<br>DRILL & REAM | | | |
| FACE MILLING<br>AREA MILLED _____ $IN^2$ | | | |
| CLEVIS-STR. MILL, DRILL, AND REAM<br>NO. _____ SIZE _____ | | | |
| MACHINING COST (UNIT 200) PER PART | | | |
| LEARNING CURVE FACTOR (SEE BELOW) | | | |
| LABOR RATE | | $ /HR | $ /HR |
| RECURRING MACHINING COST/PART* | | $ | |
| NONRECURRING TOOLING COST (NRTC) | | | $ |

*RECURRING MACHINING COST/PART =
UNIT 200 COST/PART × LEARNING CURVE FACTOR × LABOR RATE.

| DESIGN QUANTITY | LEARNING CURVE FACTOR | DESIGN QUANTITY | LEARNING CURVE FACTOR |
|---|---|---|---|
| 1 | 2.25 | 200 | 1.17 |
| 10 | 1.79 | 350 | 1.06 |
| 25 | 1.59 | 500 | 1.02 |
| 50 | 1.44 | 750 | 0.96 |
| 100 | 1.30 | 1000 | 0.92 |

90% LEARNING CURVE FACTOR TO CONVERT UNIT 200 FORMAT COST TO CUMULATIVE AVERAGE COST FOR VARIOUS DESIGN QUANTITIES.

PROGRAM COST =
(_____ × _____ + _____ ) × _____ = _____
RECURRING MACHINING COST — DESIGN QUANTITY — NRTC — INFLATION FACTOR**

TOTAL COST PER PART = PROGRAM COST/DESIGN QUANTITY = _____ / _____ = _____

**INFLATION FACTOR SUPPLIED BY USER'S COMPANY.

FTR450261000U
3 Jan 1983

# DOCUMENT REQUEST ORDER FORM

SUBMIT DOCUMENT REQUESTS TO: **AFWAL/MLTC**
**ICAM Program Library**
**Wright-Patterson AFB, OH 45433**

WITH COPY TO: **Bryan R. Noton**
**Battelle's Columbus Laboratories**
**505 King Avenue, Columbus, Ohio 43201**

| VOLUME NUMBER AND MANAGEMENT NUMBER | TITLE OF DOCUMENT | INDICATE ( ✓ ) DOCUMENT REQUESTED |
|---|---|---|
| VOLUME I (FTR450261000U) | Airframe User's Manual, Volume 1 | |
| VOLUME II (FTR450261000U) | Airframe User's Manual, Volume 2 | |
| VOLUME III (FTR450261000U) | Airframe User's Manual, Volume 3 | |
| VOLUME IV (FTR450262000U) | Electronic Design User's Manual, Volume 1 | |
| VOLUME V (JUNE 1984) | Project Summary | |
| VOLUME VI (JUNE 1984) | Technology Transfer Summary and Report Contents | |

PLEASE PRINT

**NAME:** _____ **MAIL CODE:** _____

**TITLE:** _____

**DEPARTMENT:** _____

**COMPANY:** _____

**STREET OR P.O. BOX:** _____

**STATE:** _____ **ZIP:** _____

REQUIREMENT FOR DOCUMENT

**Document(s) requested for the purpose of (intended use and program/project application must be provided):**

_____

_____

_____

_____

**Documents generated under the contract contain controlled distribtion and export control clauses.**

**I am a U.S. citizen, I am employed by a U.S. organization/company and am aware that the use of these Air Force documents must comply with:**

U.S. EXPORT CONTROL LAWS

This document contains information for manufacturing or using munitions of war. Export of the information contained herein, or release to foreign nationals within the United States, without first obtaining an export license, is a violation of the International Traffic in Arms Regulations. Such violation is subject to a penalty of up to 2 years imprisonment and a fine of $100,000 under 22 USC 2778

**Signature:** _____ **Date:** _____

**Telephone No.:** _____